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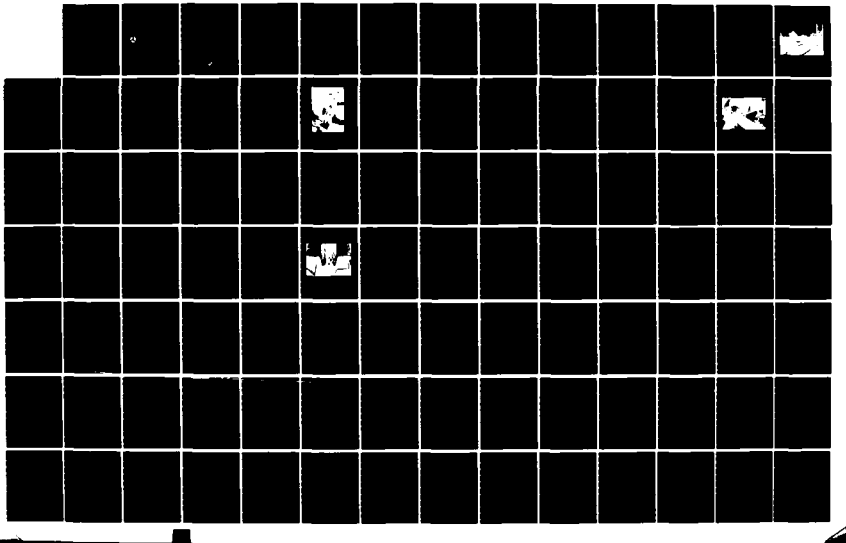

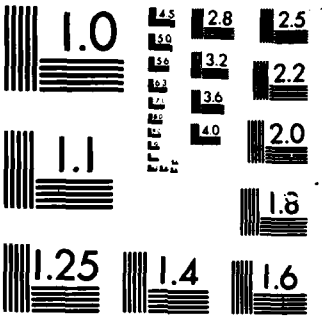


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Report No. CG-D-34-85

AD-A163 185

# ROLL-ON/ROLL-OFF AUTOMOBILE TRANSPORT SHIPS - AN ASSESSMENT OF CARBON DIOXIDE REQUIREMENTS FOR FIRE SAFETY

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FINAL REPORT
OCTOBER 1985



Prepared for:

U.S. Department Of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC 20593

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16. Abstract

This project provided an experimental assessment of the U.S. Coast Guard (USCG) requirements for carbon dioxide ($CO_2$) application rates on a Roll-On/Roll-Off ship. The assessment used a series of full-scale fire tests to determine the relative effectiveness of Safety of Life at Sea (SOLAS) and USCG requirements. The fire tests were conducted in a cargo hold of the MAYO LYKES modified to simulate a Roll-On/Roll-Off automobile carrier. The results of these tests indicated that the SOLAS carbon dioxide requirements were sufficient to extinguish flammable fuel fires and automobile fires in a cargo hold.

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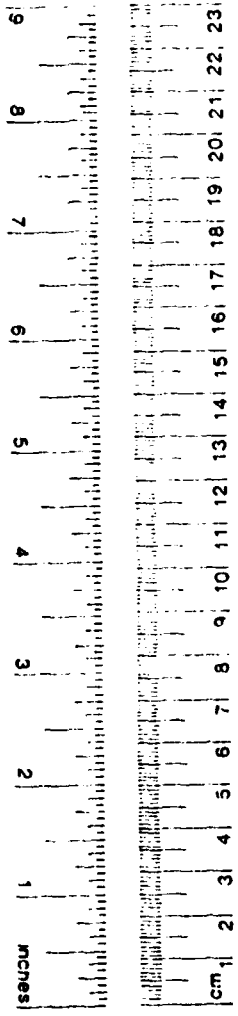
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

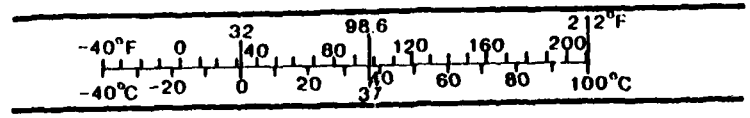
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | **AREA** | | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | **MASS (WEIGHT)** | | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | **VOLUME** | | | |
| tsp | teaspoons | 5 | milliliters | ml |
| tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | **TEMPERATURE (EXACT)** | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10:286




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | **AREA** | | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | **MASS (WEIGHT)** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | **VOLUME** | | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 0.125 | cups | c |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | **TEMPERATURE (EXACT)** | | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## FORWARD

This report was prepared by the Marine Fire Research Branch, Ocean Science and Technology Division of the U.S. Coast Guard Research and Development Center, Avery Point, Groton, Connecticut. The project number assigned for this work was 3308.08.41. The experimental tests were conducted over a four week period in February 1985.

The experimental work was conducted by the U.S. Coast Guard Fire and Safety Test Detachment, Mobile, Alabama under the supervision of CWO Robert Cushing. The project officer was Mr. Michael Friel. The Program Manager (CVS) was Dr. Alan Schneider. Mr. Ronald Martin and Mr. Larry Pritchard of Chemetron, Inc. provided technical assistance in the form of detailed engineering calculations, $CO_2$ nozzles and construction practice review. Mr. David Beene made the roll-on/roll-off ship construction surveys. Data acquisition and reduction was provided by T. Kalayanapu and R. Layne. The author acknowledges the assistance and advice of the above individuals.

This report is a final report outlining the tests performed and their results and concludes work on Project 3308.08.41. The results obtained on this project provided the technical basis for changes in U.S. Coast Guard regulations effective 22 May 1985.

## 1.0 OBJECTIVE/SUMMARY

The major objective of this project was to provide an experimental assessment of the U.S. Coast Guard (USCG) requirements for carbon dioxide ($CO_2$) application rates on a Roll-On/Roll-Off ship. The assessment used a series of full-scale fire tests to determine the relative effectiveness of Safety of Life at Sea (SOLAS) and USCG requirements. The fire tests were conducted in a cargo hold of the MAYO LYKES modified to simulate a Roll-On/Roll-Off automobile carrier. The results of these tests indicated that the SOLAS carbon dioxide requirements were sufficient to extinguish flammable fuel fires and automobile fires in a cargo hold.

## 2.0 BACKGROUND

In a recent reflagging of a ship for Roll-On/Roll-Off service it was required that the on-board carbon dioxide fire protection system be modified to meet U.S. Coast Guard regulations. The ship had been designed and built to conform with the SOLAS requirements. The changes required upgrading the carbon dioxide fire extinguishing system with respect to the rate of $CO_2$ discharge. The total quantity of $CO_2$ required to be available for use was the same for both sets of regulations (22 cubic ft/lb $CO_2$). The USCG requirements (46 CFR[+]) specify the delivery of 100 percent of the $CO_2$ in two minutes. The SOLAS requirements (SOLAS 1974, as amended*) specify the delivery of 66 2/3 percent of the $CO_2$ in ten minutes. A substantial cost penalty was incurred as a result of these changes. Experimental data was needed to determine whether the more stringent USCG requirements are necessary.

## 3.0 PROBLEM STATEMENT AND TECHNICAL APPROACH

### 3.1 Problem Statement

Carbon dioxide extinguishes fires by reducing the oxygen concentration to a point where the atmosphere will no longer support combustion.

---

[+] CFR 46, 95.15-5f, 76.15-5f

* Amendments to the International Convention for the Safety of Life at Sea, 1974, 1981 Amendment, Chapter II-2-Reg.53-Section 2.2.1.1 (page 150)

The $CO_2$ concentration must be maintained for a sufficient period to allow the temperature to be reduced below the autoignition temperature of the burning material. Carbon dioxide is highly effective against flammable liquid fires.

The required quantity and rate of application of $CO_2$ is based on a combination of small-scale experimental fire test data and professional engineering judgement. Typically, in small-scale tests an open pan of flammable liquid fuel is ignited on the floor of a burn room and a $CO_2$ discharge is made from a ceiling location. The required application rate is determined by the time needed for fire control and extinguishment.

A major difference between laboratory test fires and a flammable liquid fire on a Roll-On/Roll-Off vessel carrying automobiles is the obstruction to $CO_2$ flow resulting from the ship compartmentation and automobile cargo. Large-scale fire data was needed to provide quantitative information about the distribution and flow of $CO_2$ in Roll-On/Roll-Off cargo spaces and its effect on the fire extinguishment process.

## 3.2 Technical Approach

A three-phase program of work was developed to obtain the information needed. Phase I consisted of a background survey of currently operating Roll-On/Roll-Off ships. The investigation included a survey of Roll-On/Roll-Off ships operating under SOLAS regulations and a review of USCG databank and American Bureau of Ships listings for U.S. flag vehicle carriers. The survey and review included an evaluation of the $CO_2$ fire suppression systems on two existing ships.

The Phase II work effort provided experimental data under realistic large-scale fire conditions. The test fires were conducted in the #3 hold of the MAYO LYKES using a 3x6 array of automobiles installed on the 2nd deck. A total of 18 large-scale fire tests were conducted. These tests simulated the $CO_2$ application flow rates required by SOLAS and USCG regulations. The fire scenario simulated a gasoline spill from a ruptured fuel tank or a portable gasoline fuel container. To provide a "worse case" accident, each test used

two simultaneous fire incidents under adjacent automobiles. The area of the gasoline spill for each incident was limited to a 21"x21" pan fire with sufficient fuel for a 10-12 minute burn. The test documented the time to control/extinction of two flammable fuels; gasoline and mineral spirits. Video coverage, thermocouple data at selected locations, $CO_2$ and $O_2$ concentrations at selected locations, and the application rate of $CO_2$ were used and/or measured to provide detailed information for engineering analysis.

The Phase III work effort involved the reduction of data and analysis of results. The reduction of data included the development of tables and graphs summarizing the experimental results. The analysis of results included an evaluation of the time to control/extinction together with an estimation of $O_2$ and of $CO_2$ gas distributions in Roll-On/Roll-Off cargo spaces.

## 4.0 EXPERIMENTAL

### 4.1 General

A number of previous investigators have examined the minimum $CO_2$ requirements needed to control and extinguish flammable fuel fires. In general, these investigators have utilized small-scale fire test data to estimate the required quantities and application rates needed to control and extinguish large-scale fires. The basic premise for such estimates is that data from smaller laboratory fires can be scaled to predict fire extinguishment and control phenomena for large-scale ship cargo holds.

A major difficulty in developing these scaling factors is to describe $CO_2$ dispersement, and mixing and ventilation process effects. In order to accurately represent these effects a large-scale experimental test program was developed. The experimental model simulated a cargo hold in a Roll-On/ Roll-Off ship by testing an array of automobiles contained in a cargo hold in the USCG fire test ship MAYO LYKES (Figure 1). This large-scale test approach is believed to provide a more reliable basis for the development of fire safety regulations for ships.

FIGURE 1. MAYO LYKES - #3 CARGO HOLD

In order to provide a margin of safety, the quantities of $CO_2$ that were used were somewhat less than the quantities prescribed by SOLAS and USCG regulations. The point of view adopted was that if during the early tests it became apparent that fire control/extinguishment could not be achieved using these conservative quantities of $CO_2$ then the quantity could be increased. If, on the other hand, it was effective then extrapolation of results to specific cargo vessels could be made with a higher degree of confidence.

## 4.2 Fire Scenario

The fire scenario chosen assumed the major threat was spilled fuel from a ruptured tank or portable gasoline container. Discussions with the ship operators indicated that for new automobile cargoes a minimum of gasoline or diesel fuel was carried in the automobile tanks. Observations during the surveys indicated that 5-gallon portable containers were used to refuel the automobiles. Therefore, a 5-gallon spill fire was assumed to be a most realistic fire scenario. To simulate this type of spill, a pan fire was used to represent the initial fire stage, before the fire spread to the vehicle. The fire threat was limited to an area of 21"x21" and five gallons of fuel. Two types of fuel were used: gasoline and mineral spirits (to simulate diesel oil fires). During testing the fuel pans were placed directly under the gasoline tank of a test automobile to simulate the most probable spill location. Prior to testing all fuel tanks were emptied and vented to prevent explosion. The total fire threat thus consisted of the flammable fuel fire together with the Class A fire load associated with tires, upholstery and other automotive components.

During Phase I of this project, a survey was made of two foreign flag Roll-On/Roll-Off ships. One of the results of this survey was the observation that multi-deck cargo spaces were commonly employed with the $CO_2$ nozzles located on the upper areas. The use of open grating decking allowed the dispersement of $CO_2$ to the lower volumes of a cargo hold. Such an arrangement together with closely spaced cargo could restrict the transport of $CO_2$ to a fire on a lower deck. To evaluate the effect of such restrictions, a series of four tests were conducted in which a "false" overhead was constructed above the automobile array. The false deck was fabricated from

corrugated siding and light steel supports. The $CO_2$ discharge nozzles were above the decking and the flow of $CO_2$ was similar to that expected on typical Roll-On/Roll-Off ships. On such ships an open grating decking was present along the "sides" of the cargo space.

## 4.3 Test Program

The test program was divided into five major tasks. Task 1 consisted of a series of four "cold flow" tests designed to verify the operation of the low pressure $CO_2$ piping, valving, and nozzle subsystems. Task 2 investigated mineral fuel fires (4 tests) from an open single deck. Task 3 investigated gasoline fires (4 tests) for an open single deck. Task 4 provided information on gasoline fires with an overhead false deck. Task 5 consisted of a single "worse case" test in which the fire threat was generated by saturating the interior of the automobiles with gasoline as well as by the spill fire pans. For Task 5, the more conservative SOLAS carbon dioxide quantity and rate limits were used for extinguishment. The fire test "time line" consisted of the following sequence: (1) a 2-minute preburn in both fuel pans, (2) an application of $CO_2$ at a rate similar to those specified by SOLAS and USCG regulations, (3) a holding period for mixing of $CO_2$ with the cargo hold air, and (4) control/extingishment of the fire.

## 4.4 The Automobile Array

For this test series, eighteen automobiles were placed in the #3 hold of the MAYO LYKES. The areas used (indicated by the shading in Figure 2) included the 2nd deck, the 1st platform deck in the #3 hold, and the forward cabins on the boat deck. The automobiles were located on the 2nd deck which had been partitioned with a steel bulkhead. The fire test area had a total volume of 37,470 cubic feet and a length of 55 feet. Instrumentation was located on the 1st platform deck, on the 2nd deck of the #2 cargo hold and on the boat deck. Hatches on the #3 hold were in place but not sealed.

The automobiles were installed in a three by six array. The assigned locations for individual autos are indicated in Figure 3. The automobiles were installed using a minimum of space. Generally a distance of separation of less than two feet was maintained between adjacent autombiles

SHADED AREA IS KEY TO PLAN SHOWN ON THIS SHEET

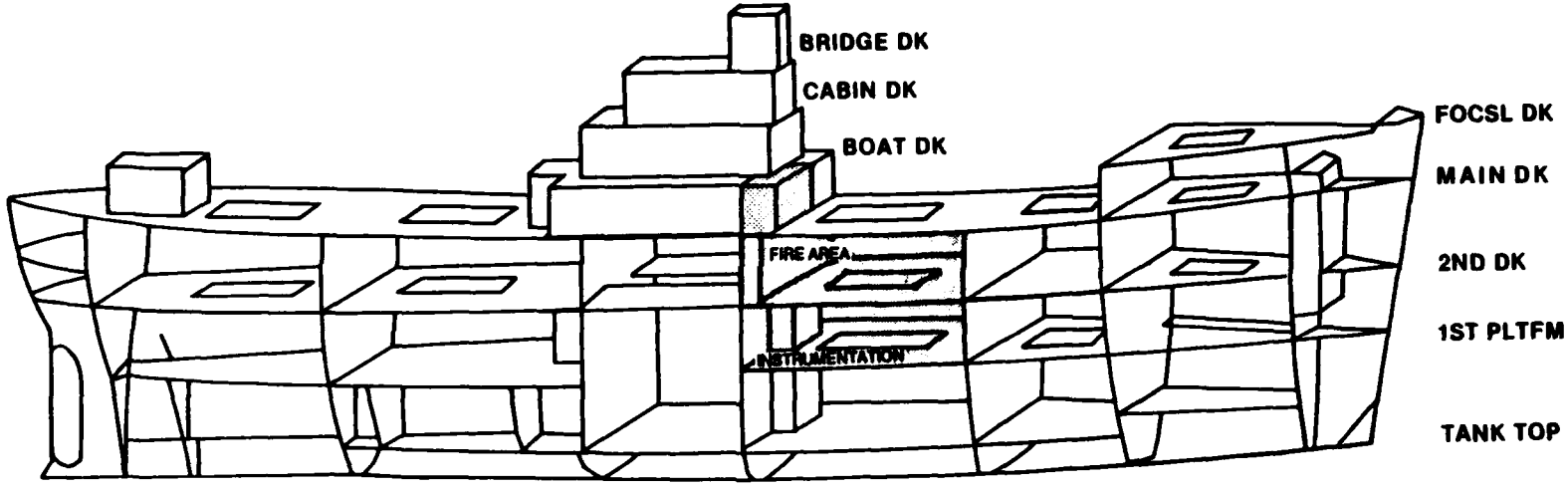



FIGURE 2. FIRE TEST AREA ON MAYO LYKES

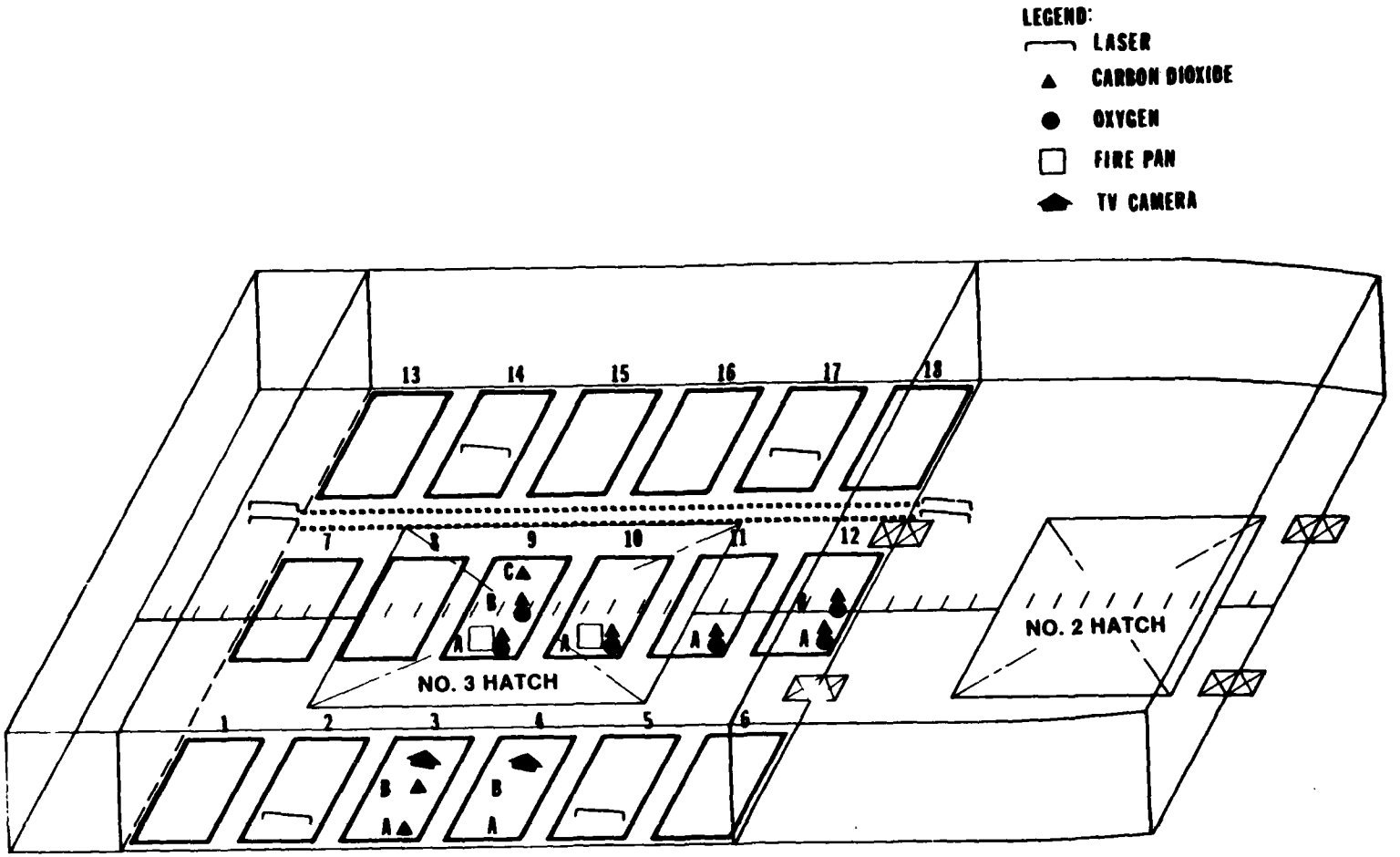



FIGURE 3. LOCATIONS OF AUTOMOBILES IN #3 CARGO HOLD

( A, B, & C are Instrument Locations see Figure - 8 )

and bumpers. An exception to this was the lane where the pan fires were set. In this case a 3-foot lane was used in order to allow room for video monitoring equipment and personnel access during fuel loading (Figure 4). The close spacing was made in order: (1) to simulate actual shipboard conditions as closely as possible, and (2) to determine whether the fire would propagate from auto to auto in a closely packed array.

As a worse case scenario it was assumed that two adjacent spill incidents might occur. Therefore, all testing utilized two simultaneous pan fires in adjacent automobiles, Auto 9A and Auto 10A. This arrangement enabled a determination of whether interactive effects between two fires were important. Also, this arrangement doubled the number of extinguishment data test points without an increase in experimental effort.

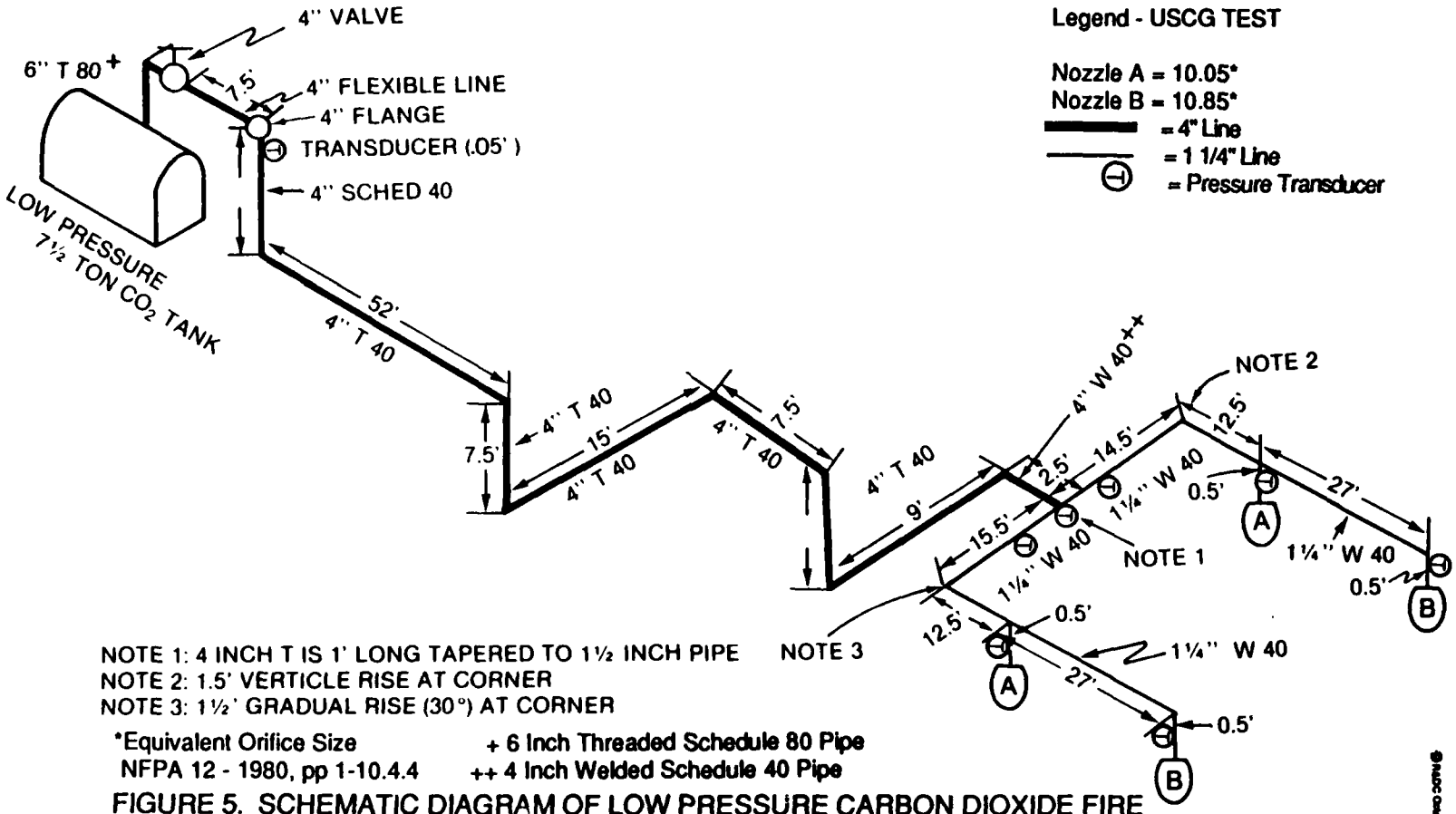
### 4.5 Fuels

The study included an evaluation of two liquid fuels: gasoline and mineral spirits. Mineral spirits, a fuel less volatile than gasoline was used in the early tests for safety reasons. Mineral spirits fires are similar to diesel fuel fires. A commercial brand of unleaded gasoline (Texaco 87 octane) was used for all gasoline fires, and commercial grade mineral spirits were used for the simulated diesel oil fires.

### 4.6 The Carbon Dioxide System

A low pressure carbon dioxide system was used for all tests. The system consisted of the following components: (1) a low presure 7-1/2 ton Cardox tank, (2) a 4-inch main valve, (3) a 4-inch stainless steel flexible line, (4) approximately 155 feet of piping, and (5) nozzles. In-line pressure transducers were installed to measure dynamic pressure changes at selected tank and line locations. Pressures were measured at the tank, along the line, and at the nozzles. The principal differences between the SOLAS and USCG tests involved the line pipe sizes and the nozzle orifices. For the USCG tests a 4-inch main line was used. This line was reduced to a branched 1-1/4 inch line in the fire test hold volume. For the SOLAS tests a 3/4-inch line reduced to 1/2-inch was used. Schematic diagrams of the carbon dioxide

FIGURE 4. FIRE TEST PAN IN THE AUTOMOBILE ARRAY

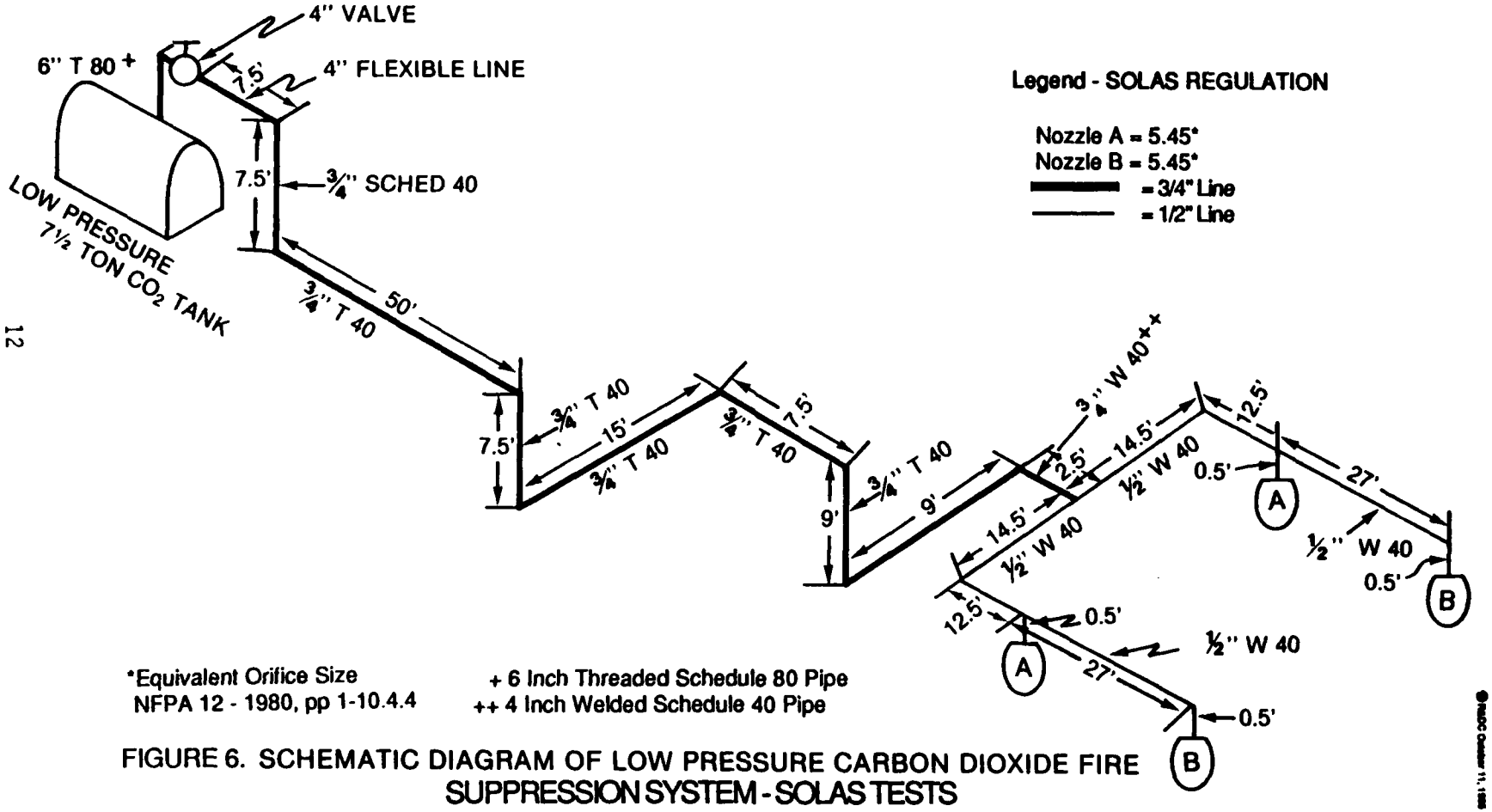



NOTE 1: 4 INCH T IS 1' LONG TAPERED TO 1½ INCH PIPE
NOTE 2: 1.5' VERTICLE RISE AT CORNER
NOTE 3: 1½' GRADUAL RISE (30°) AT CORNER

*Equivalent Orifice Size
NFPA 12 - 1980, pp 1-10.4.4

+ 6 Inch Threaded Schedule 80 Pipe
++ 4 Inch Welded Schedule 40 Pipe

FIGURE 5. SCHEMATIC DIAGRAM OF LOW PRESSURE CARBON DIOXIDE FIRE SUPPRESSION SYSTEM - USCG TESTS




*Equivalent Orifice Size
NFPA 12 - 1980, pp 1-10.4.4

\+ 6 Inch Threaded Schedule 80 Pipe
++ 4 Inch Welded Schedule 40 Pipe

FIGURE 6. SCHEMATIC DIAGRAM OF LOW PRESSURE CARBON DIOXIDE FIRE SUPPRESSION SYSTEM - SOLAS TESTS

systems are shown in Figures 5 and 6. The nominal main tank operating pressure was 300 psi. However, because of difficulties in maintaining this pressure on consecutive tests, lower operating pressures were used for many tests. The first four tests were "cold flow" tests to verify the functionality of the system. Changes made during Tests 1-4 included modifying a blind flange transition section between the 4-inch flexible line and the SOLAS main line to a more gradual transition section and reballasting the ship to allow accurate carbon dioxide weight measurements. The two main lines (SOLAS and USCG) were run side-by-side to minimize systematic variations due to pipe run lengths and elevation drop factors.

### 4.7 Instrumentation

A brief listing of instrumentation that was used is given in Appendix A. The locations refer to the distance in feet from the point of origin at the aft-starboard corner of the #3 cargo hold (Figure 7). A brief summary of the instrumentation that was used is described as follows:

a. Weight loss of $CO_2$. Transducers were used to measure the dynamic weight changes in the Cardox tank. Weight loss per test ranged from 500 to 1600 lbs. The precision of measurement was estimated to be $\pm$ 20 lbs.

b. Forty-three (43) thermocouples were installed in the cargo hold to monitor the propagation of the fire. Two thermocouples were mounted above the fire pans to monitor the time/temperature history of the fire.

c. $O_2$ gas analyzers. Six paramagnetic oxygen analyzers were used to measure $O_2$ concentrations at critical locations. Two of these locations were immediately above the fire pans.

d. $CO_2$ gas analyzers. Nine analyzers were used to measure $CO_2$ concentrations in the fire hold. Three additional analyzers were used to evaluate personnel safety hazards in the instrumentation area.

e. Line Pressure Transducers for $CO_2$ piping.

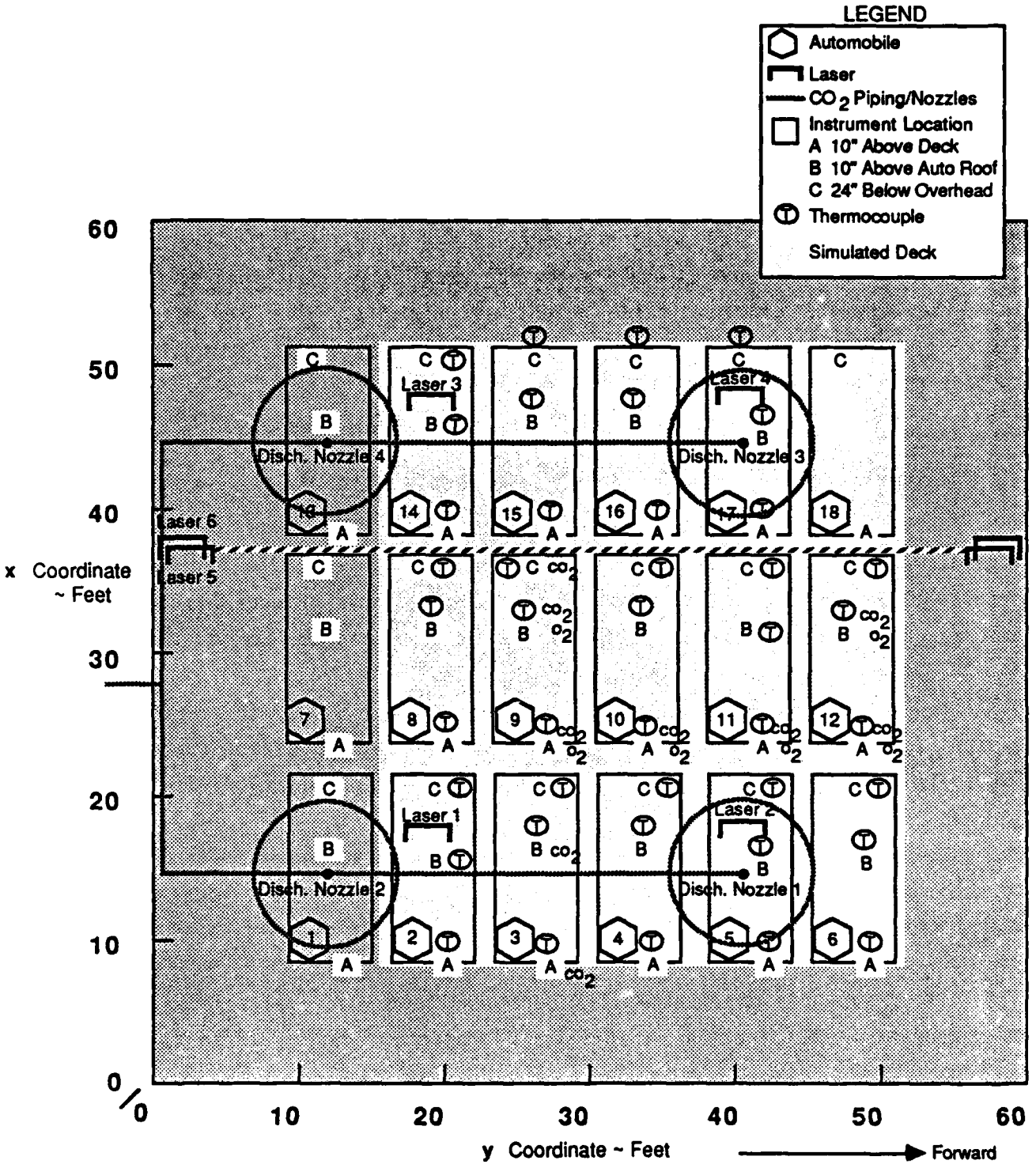



FIGURE 7. COORDINATE SYSTEM - INSTRUMENTATION LOCATION - $CO_2$ PIPING AND NOZZLES

f. Optical Density of Smoke. Six lasers were used to monitor the optical transmission of red light (He-Ne laser) through the "smoke" produced by the fire and the $CO_2$ discharge.

g. Video cameras. Three video cameras were used to provide visual information on the ignition and extinguishment of the test fires.

An elevation view of the location of instrumentation with respect to a typical automobile is shown in Figure 8. Because the height of the overhead varied due to the hatch cover, the distance of 24" from the overhead is only approximate.

## 5.0 RESULTS

### 5.1 General

In the interest of conciseness, the reported data are limited to that required for a documentation and understanding of the main program objectives. The reported results include data for the following experimental parameters:

- o Weight loss for the Cardox $CO_2$ system
- o Optical density
- o Time/temperature above the fire pans
- o Percent oxygen at selected locations
- o Percent carbon dioxide at selected locations
- o Extinguishments/non-extinguishments
- o Quantity of fuel burned

The data is presented graphically in Appendix B by test number. A brief outline of the data and their format of presentation is provided in the following sections. Figure 9 shows a fire pan and automobile after a typical test.

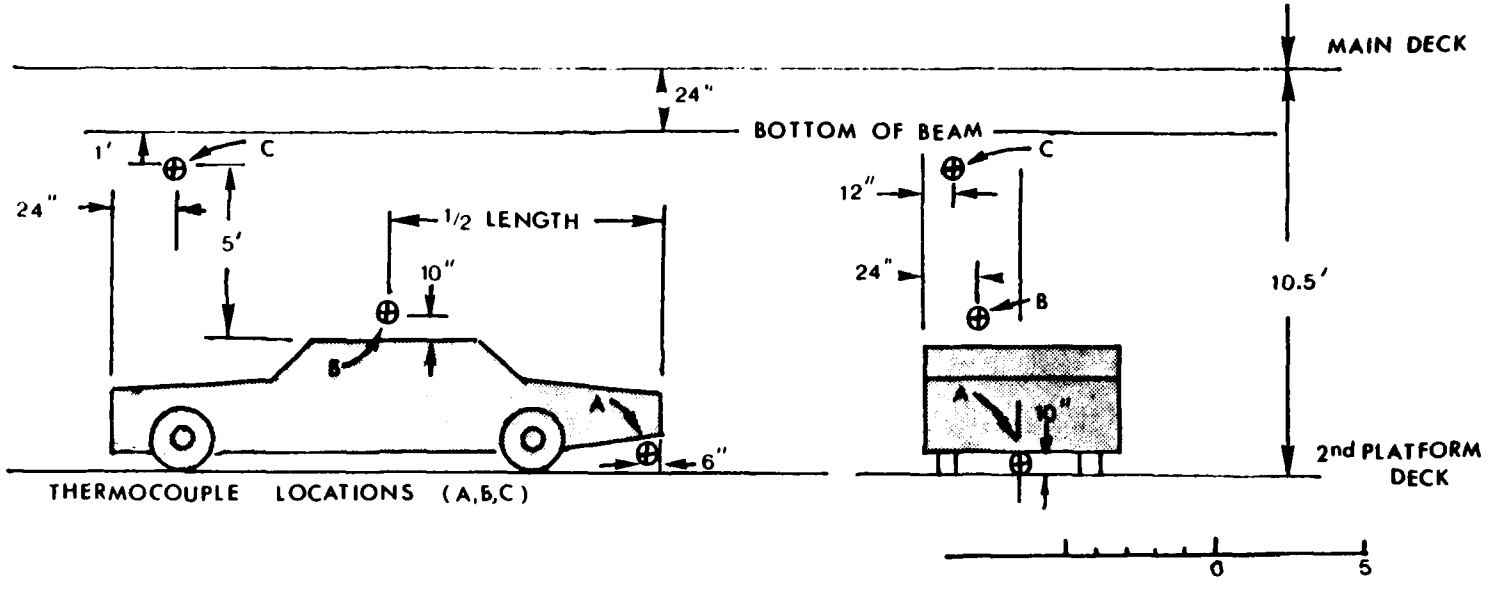



FIGURE 8. INSTRUMENTATION LOCATIONS A, B, AND C WITH RESPECT TO A TYPICAL TEST AUTOMOBILE

FIGURE 9. FIRE PAN AND AUTOMOBILE AFTER A TYPICAL TEST

## 5.2 Weight Loss of Carbon Dioxide

The Cardox tank was suspended on flexible chains attached to load transducers. The dry weight of the tank was 12,500 lbs. and the total weight with contents varied from 14,000 to 26,000 lbs. The precision of measurement is estimated to be at least ±20 lbs. Weight loss data is presented for each test in Appendix B. For clarity of presentation, the ordinate is adjusted to 0 to 2000 lbs. Indicated on each plot is the total weight of $CO_2$ discharged and the rate of discharge. This data is summarized in Tables I and II. Table I indicates the carbon dioxide discharge times for the test time at end of discharge, and the total discharge time. For most tests, the total discharge time differs from the test time at end of discharge by the constant 2-minute preburn time. The discharge times ranged from 2.0 to 12.8 minutes. Associated with each discharge time is a rate of discharge. The rate of discharge is a function of the nozzle size, main tank pressure, and discharge time. Discharge rates for carbon dioxide are summarized in Table II. The discharge rates varied from 87 to 810 lbs. (39 to 368 kg) per minute.

## 5.3 Optical Density

The optical density of the smoke in the cargo area was measured using a He/Ne laser system. Six lasers were used. Four were located in position B on the auto as indicated in Figure 8. The emitter and receiver for these lasers were separated by a one meter distance. Two laser systems were positioned at 4-1/2' and 8' above the deck with the emitter separated from the receiver by a distance of 16.72 meters.

The optical density (OD) was calculated using Beers Law:

$$OD = \left[ \log_{10} \frac{I_o}{I} \right] \div L \qquad (5.3.1)$$

where: $I_o$ = the light intensity with no smoke present
$I$ = the light intensity with smoke present
$L$ = optical pathlength in meters

The optical density data is presented on two graphs for each test in Appendix B. The first plot shows the data for the one meter channels

TABLE I

CARBON DIOXIDE DISCHARGE TIMES

| | Test Time at End of Discharge (minutes) | Discharge Time* (minutes) |
|---|---|---|
| Task 1. Cold Flow | | |
| Test 1 | 3.0 | 3.0 |
| Test 2 | 6.5 | 4.5 |
| Test 3 | 14.5 | 12.5 |
| Test 4 | 13.5 | 11.5 |
| Task 2. Mineral Spirits - Single Deck | | |
| Test 5 | 14.8 | 12.8 |
| Test 6 | 14.3 | 12.3 |
| Test 7 | 5.0 | 3.0 |
| Test 8 | 5.5 | 3.5 |
| Task 3. Gasoline - Single Deck | | |
| Test 9 | 5.8 | 3.8 |
| Test 10** | 7.0 | 5.0 |
| Test 11 | 14.5 | 12.5 |
| Test 12 | 14.5 | 12.5 |
| Test 13 | 4.5 | 2.5 |
| Task 4. Gasoline - Two Deck | | |
| Test 14 | 4.0 | 2.0 |
| Test 15 | 4.0 | 2.0 |
| Test 16 | 13.6 | 11.6 |
| Test 17 | 13.5 | 11.6 |

* Adjusted for preburn time

** Test aborted due to lack of $CO_2$

TABLE II

CARBON DIOXIDE DISCHARGE RATES

| | Weight of $CO_2$ lbs | kg | Rate of $CO_2$ Discharge lbs/min | kg/min |
|---|---|---|---|---|
| Task 1. Cold Flow | | | | |
| Test 1 | 1570 | 712 | 523 | 237 |
| Test 2 | 440 | 199 | 98 | 44 |
| Test 3 | 1270 | 576 | 102 | 46 |
| Test 4 | 1105 | 501 | 96 | 44 |
| Task 2. Mineral Spirits - Single Deck | | | | |
| Test 5 | 1115 | 505 | 87 | 39 |
| Test 6 | 1122 | 509 | 91 | 41 |
| Test 7 | 1470 | 667 | 490 | 222 |
| Test 8 | 1475 | 669 | 421 | 191 |
| Task 3. Gasoline - Single Deck | | | | |
| Test 9 | 1500 | 680 | 395 | 179 |
| Test 10 | 1082 | 491 | 216 | 98 |
| Test 11 | 1120 | 508 | 90 | 41 |
| Test 12 | 1160 | 526 | 93 | 42 |
| Test 13 | 1618 | 734 | 647 | 294 |
| Task 4. Gasoline - Two Deck | | | | |
| Test 14 | 1620 | 735 | 810 | 368 |
| Test 15 | 1580 | 716 | 790 | 358 |
| Test 16 | 1125 | 510 | 98 | 44 |
| Test 17 | 1128 | 511 | 97 | 44 |

(Channels 2, 3, 4, and 5). The second plot shows the data for the 16.72 meter path length (Channels 6, 7). The estimated optical density limiting values are listed for each channel. These limiting values were calculated by using a statistical analysis of the laser system noise in a time period immediately preceding each test. The limiting optical density at low light levels was defined as the calculated optical density when the low level signal is equal to the pre-test noise level. In using this parameter, the validity of any experimental data where the measured OD exceeds the limiting value is assumed questionable. For example, for Test 15 the limiting value for the one meter channels varies from 1.87 to 2.49, whereas the limits for the 16.72 meter path length range from .11 to .12. Any optical density data having higher values are considered to be out of range. For Tests 1-4, the increase in optical density is primarily due to formation of particulated solid carbon dioxide. In the remainder of the tests (involving active fires), the observed optical densities are a combination of the smoke produced by the fire, solid carbon dioxide, dust, amd condensed water vapor.

### 5.4 Time/Temperature Above the Fire Pans

A relatively complete network of 43 thermocouples was installed in the test array of automobiles (see Appendix A). The purpose of this network was to provide information concerning the rate of fire spread between adjacent automobiles. However, since the fires did not progress beyond the fire pans and automobiles immediately above each pan (Auto 9, Auto 10), the reported data is limited to the time temperature history of the fire pans. For each test, two channels of data are reported: Channel 50 (Auto 9A), and Channel 53 (Auto 10A). Experimental data for each test is graphically presented in Appendix B. Data for Tests 1 through 4 are not reported since they involved cold flow tests required to check out the $CO_2$ system.

Characteristically, the time/temperature history can be divided into three zones; the preburn zone, the fire zone, and the control/extinguishment zone. The preburn period constitutes the first zone. With the exception of Tests 1-4, a 2-minute preburn time was used for all tests. Typically, the temperature rises to a peak of 700-800$^{o}$C during the first minute of this period and decays to about 90% of the peak value at the end of two minutes.

The time required for the initial rise varies from 30 to 45 seconds. Zone 2 can be described as a quasi-steady state combustion period. Typically, the temperature decays slowly with time until the fire control point is reached. Zone 3 involves control/extinction processes. The onset of this process is somewhat arbitrary, but in these tests it was taken to be the beginning of a relatively smooth exponential decay curve. In the data presentation, the preburn time and the onset of the control/extinction curve are shown by vertical lines. The end of the $CO_2$ discharge is also indicated. In most of the tests, the $CO_2$ discharge was completed before the control point was reached. A summary of the fire control/extinction times is given in Table III.

### 5.5 Percent Oxygen at Selected Locations

The percent oxygen was measured at six locations. Two of these locations were immediately above the fire pans (Channels 8, 9). Two were located 10" above the deck at sample stations Auto 11A and Auto 12A and two were located 10" above Autos 9 and 12 at automobile stations 9B and 12B. The time vs oxygen concentration data are summarized in Appendix B. The data was not adjusted for sample line flow lags or instrumental response times. Therefore, it is estimated the reported data may lag the actual concentrations by an estimated 30 to 210 seconds. Also reported are the percent oxygen at the control time and the minimum percent oxygen observed during each test.

### 5.6 Percent Carbon Dioxide at Selected Locations

The percent carbon dioxide was measured at nine selected locations. Five of these sample points were located 10" above the deck (9A, 10A, 11A, 12A, and 3A). Three sample points were 10" above the automobile roof lines (9B, 12B, and 3B), and one point was located in the overhead (9C). The time vs carbon dioxide concentration plots for these sample points are summarized in Appendix B together with the concentration measured at the control times and the maximums measured during the tests. No correction was made to adjust for sample system transit times and instrumental lag times.

### 5.7 Fuel Fires Extinguished

All fuel fires were extinguished during these tests.

TABLE III

PAN FIRE CONTROL/EXTINCTION TIMES

| | | Auto 9A (Minutes) | Auto 10A (Minutes) | Average (Minutes) |
|---|---|---|---|---|
| Task 1. Cold Flow | | | | |
| | Test 1 | -- | -- | |
| | Test 2 | -- | -- | |
| | Test 3 | -- | -- | |
| | Test 4 | -- | -- | |
| Task 2. Mineral Spirits - Single Deck | | | | |
| | Test 5 | 14.6 | 14.7 | 14.7 |
| | Test 6 | 13.2 | 13.8 | 13.5 |
| | Test 7 | 8.6 | 6.0 | 7.3 |
| | Test 8 | 6.8 | 7.3 | 7.0 |
| Task 3. Gasoline - Single Deck | | | | |
| | Test 9 | 5.8 | 5.6 | 5.7 |
| | Test 10 | 9.1 | 6.1 | 7.6 |
| | Test 11 | 11.3 | 12.0 | 11.7 |
| | Test 12 | 11.8 | 10.8 | 11.3 |
| | Test 13 | 3.8 | 3.6 | 3.7 |
| Task 4. Gasoline - Two Deck | | | | |
| | Test 14 | 3.8 | 3.6 | 3.7 |
| | Test 15 | 3.8 | 3.7 | 3.8 |
| | Test 16 | 13.3 | 12.2 | 12.8 |
| | Test 17 | 12.3 | 11.7 | 12.0 |

### 5.8 Quantity of Gasoline Burned

The depth of the gasoline in the fire pan was measured before and after each test. In all cases there was residual fuel in the fire pans at the end of the test indicating that the extinguishment was a result of the action of carbon dioxide and not fuel burned. Table IV, Fuel Burned, summarizes this data. The precision of the depth measurement is estimated at $\pm$ 20%.

## 6.0 DISCUSSION

### 6.1 General

Carbon dioxide is effective as an extinguishing agent against flammable fuel fires because it reduces the oxygen content of the local atmospheres in the region of the fire below the flammability limit. The limits of flammability of gasoline vapor in selected air/inert gas atmosphere has been summarized by Coward and Jones[1]. Figure 10 shows these limits for gasoline vapor, air, and carbon dioxide. As indicated the limit of flammability for this 3-component system corresponds to a minimum requirement of 14.4% oxygen. Also, as indicated, the gasoline vapor limits for these mixtures are 1.5 to 7.3% gasoline (at zero $CO_2$ content) and become narrower with the addition of $CO_2$. The carbon dioxide atmosphere must be maintained for a sufficient period to allow local temperatures in the fire zone to be reduced to below those associated with the auto-ignition temperature for the fuels. Since $CO_2$ has a relatively low heat capacity it has a limited cooling effect. These two effects, (1) the reduction of oxygen content, and (2) the holding time required to reduce temperature, are the most important parameters in assessing the effectiveness of alternative application rates for carbon dioxide.

### 6.2 Gas Concentration of Carbon Dioxide and Oxygen

Although both SOLAS and USCG regulations require the same weight of

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1 "Limits of Flammability of Gases and Vapor, Coward, H.F., and Jones, G.W., Bulletin 503, Bureau of Mines (1952)

TABLE IV

FUEL BURNED

I. GASOLINE - Single Deck Configuration

| SOLAS Test 11 | Fuel Burned (Inches) | USCG Test 9 | Fuel Burned (Inches) |
|---|---|---|---|
| Auto 9 | 1.25 | Auto 9 | .75 |
| Auto 10 | 1.25 | Auto 10 | .75 |
| SOLAS Test 12 | | USCG Test 13 | |
| Auto 9 | 1.50 | Auto 9 | .62 |
| Auto 10 | 1.25 | Auto 10 | .50 |
| Average | 1.3 | Average | .65 |

II. GASOLINE - Two Deck Configuration

| SOLAS Test 16 | Fuel Burned (Inches) | USCG Test 14 | Fuel Burned (Inches) |
|---|---|---|---|
| Auto 9 | 1.0 | Auto 9 | .25 |
| Auto 10 | 1.0 | Auto 10 | .50 |
| SOLAS Test 17 | | USCG Test 15 | |
| Auto 9 | 1.0 | Auto 9 | .50 |
| Auto 10 | 1.0 | Auto 10 | .62 |
| Average | 1.0 | Average | .46 |

III. MINERAL SPIRITS - Single Deck Configuration

| SOLAS Test 5 | Fuel Burned (Inches) | USCG Test 7 | Fuel Burned (Inches) |
|---|---|---|---|
| Auto 9 | 1.25(?) | Auto 9 | .50 |
| Auto 10 | 1.50(?) | Auto 10 | .50 |
| SOLAS Test 6 | | USCG Test 8 | |
| Auto 9 | 1.38 | Auto 9 | .25 |
| Auto 10 | 1.25 | Auto 10 | .50 |
| Average | 1.34 | Average | .44 |

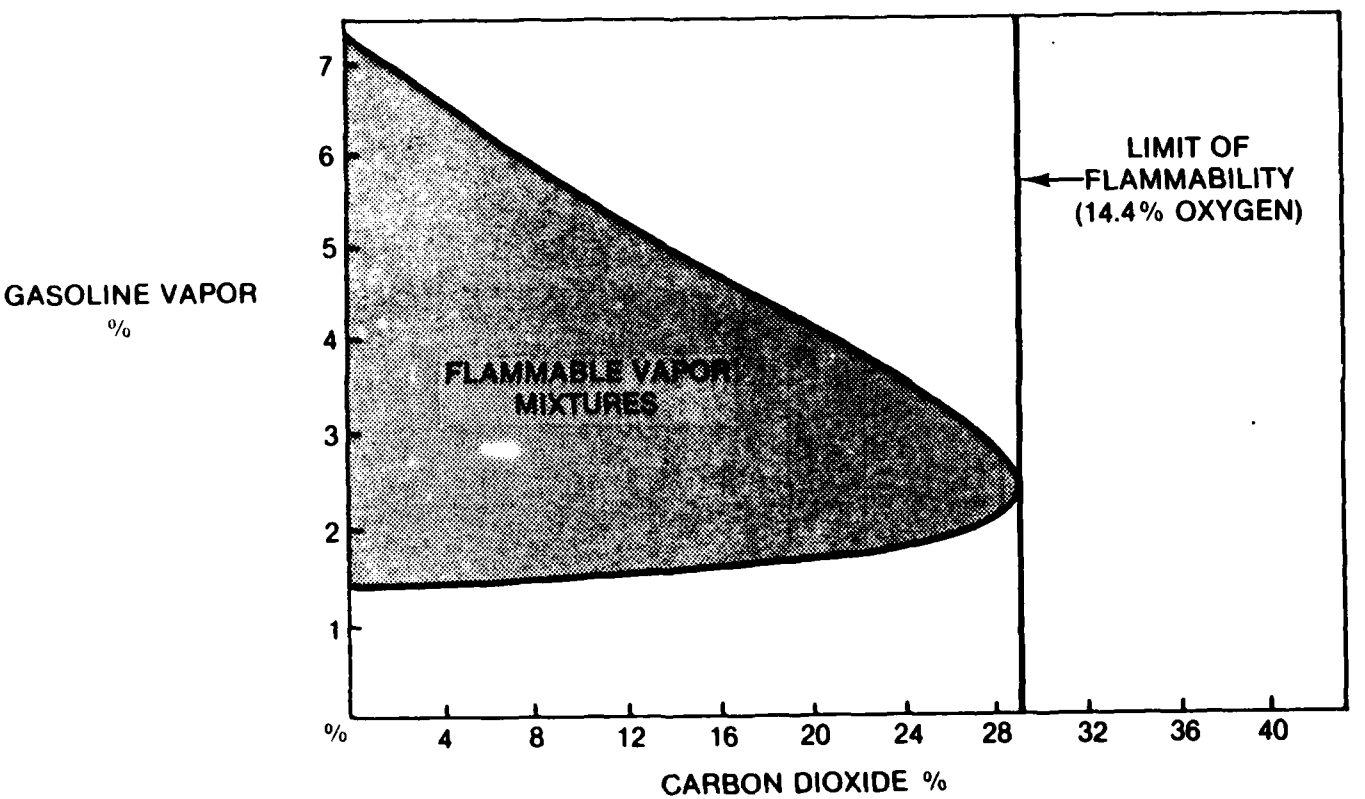


FIGURE 10. LIMITS OF FLAMMABILITY OF GASOLINE VAPOR IN MIXTURES OF AIR AND CARBON DIOXIDE

carbon dioxide, the SOLAS regulations allow a fire protection system capable of applying 2/3 of this amount within a 10-minute period whereas the USCG regulation requires a system of applying the entire amount within a 2-minute period.

The differences can be seen by a comparison of typical time/concentration plots for carbon dioxide in Figures 11a and b. Figure 11a is a composite graph showing the time concentration data for five sampling points located 10 inches above the deck for USCG Test 13. After a preburn time of two minutes (indicated by the shaded area) the $CO_2$ concentration increases rapidly to a limiting average concentration of about 30% at 5 minutes. The commonly prescribed value of 28% $CO_2$ is indicated by a horizontal line. The average concentration of $CO_2$ remains above this line for several minutes. The individual sampling points within experimental error tend to be closely grouped indicating reasonably uniform disbursement of the $CO_2$ at the 10-inch level. The data for Figures 11 and 12 were adjusted for estimated transit and instrument response time delays.

Figure 11b shows a similar plot for a typical SOLAS system. In this case the individual sample points show a more slowly increasing $CO_2$ atmosphere corresponding to the slower rate of application. In this test the $CO_2$ concentration did not reach the 28% level during the first 15 minutes of the test.

Corresponding to the dilution of the air by the $CO_2$ there is a decrease in oxygen concentration. Typical data for this decrease is shown in Figures 12a and 12b for three sampling positions 10 inches above the deck. A horizontal line indicates 14.4% oxygen, the oxygen limiting value. For the USCG system this value is reached at about seven minutes (Figure 12a). For the SOLAS system (Figure 12b) this value is not reached before 15 minutes.

### 6.3 Characterization of the Flammable Fuel Fires

Figures 13a and 13b show the time/temperature history above the fuel pan for USCG and SOLAS rates of application. The general form of the curve indicates a rapid rise in temperature to about 700°C in the fire plume

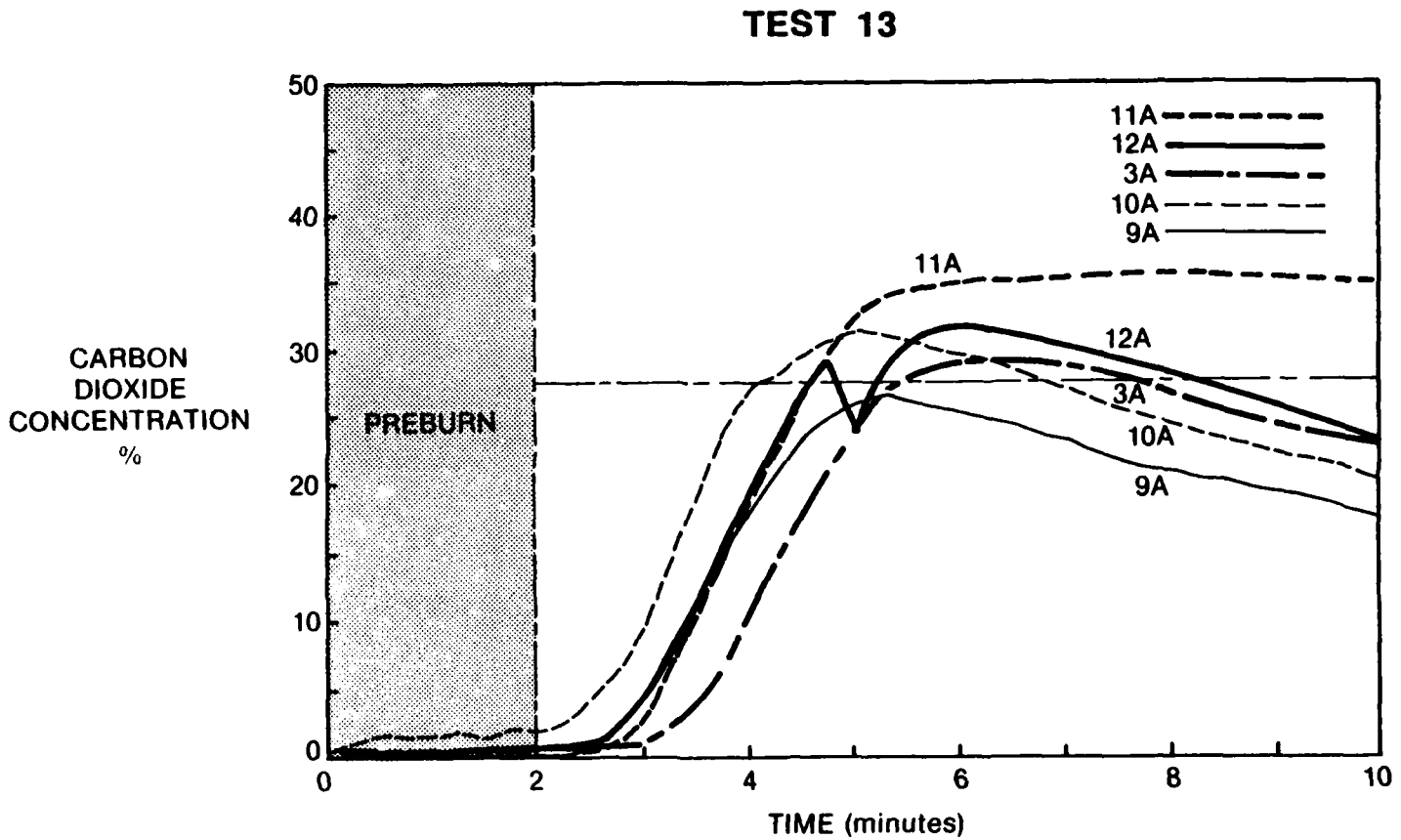


FIGURE 11a. CARBON DIOXIDE CONCENTRATION TEN INCHES ABOVE DECK - USCG SINGLE DECK

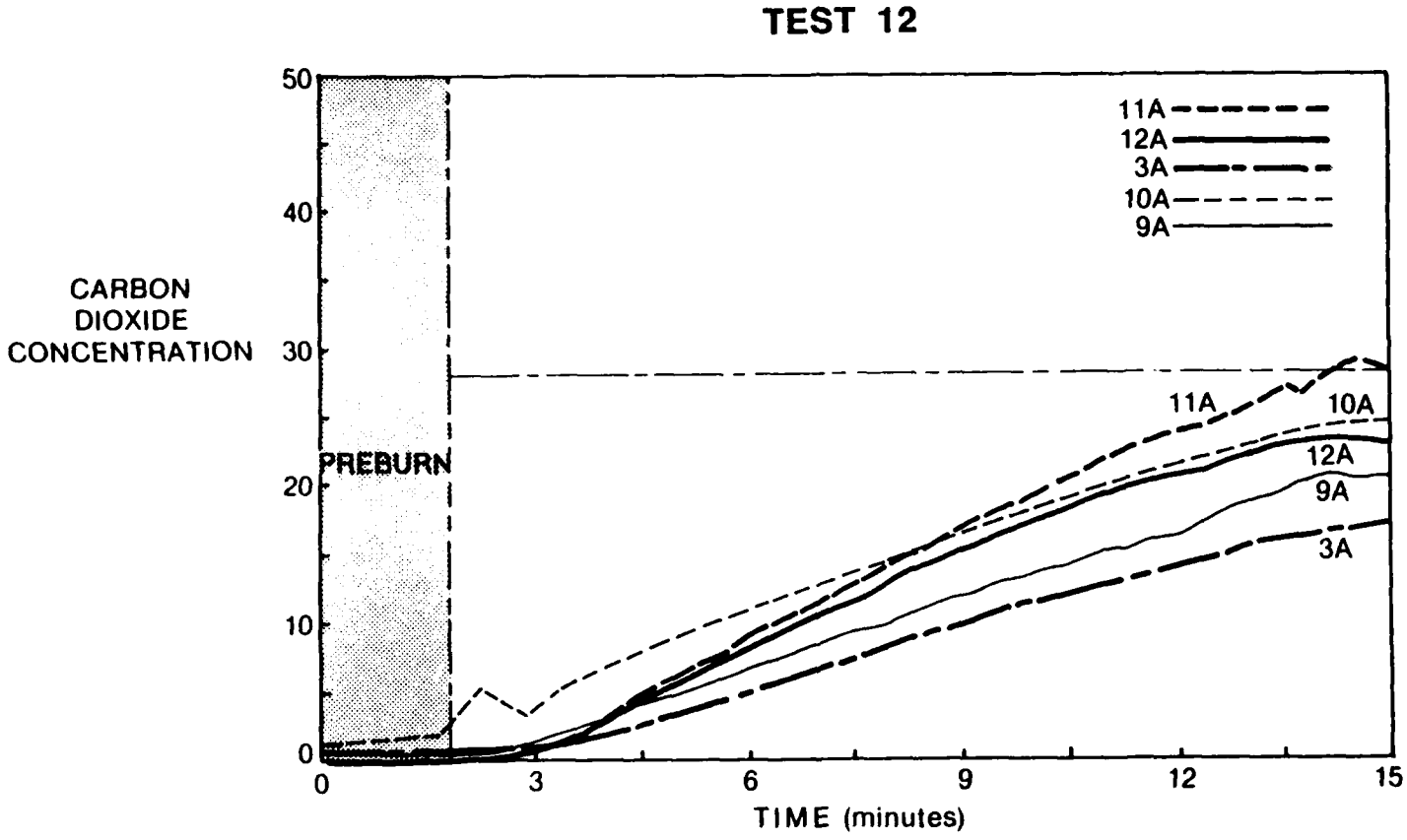


FIGURE 11b. CARBON DIOXIDE CONCENTRATION TEN INCHES ABOVE DECK - SOLAS, SINGLE DECK

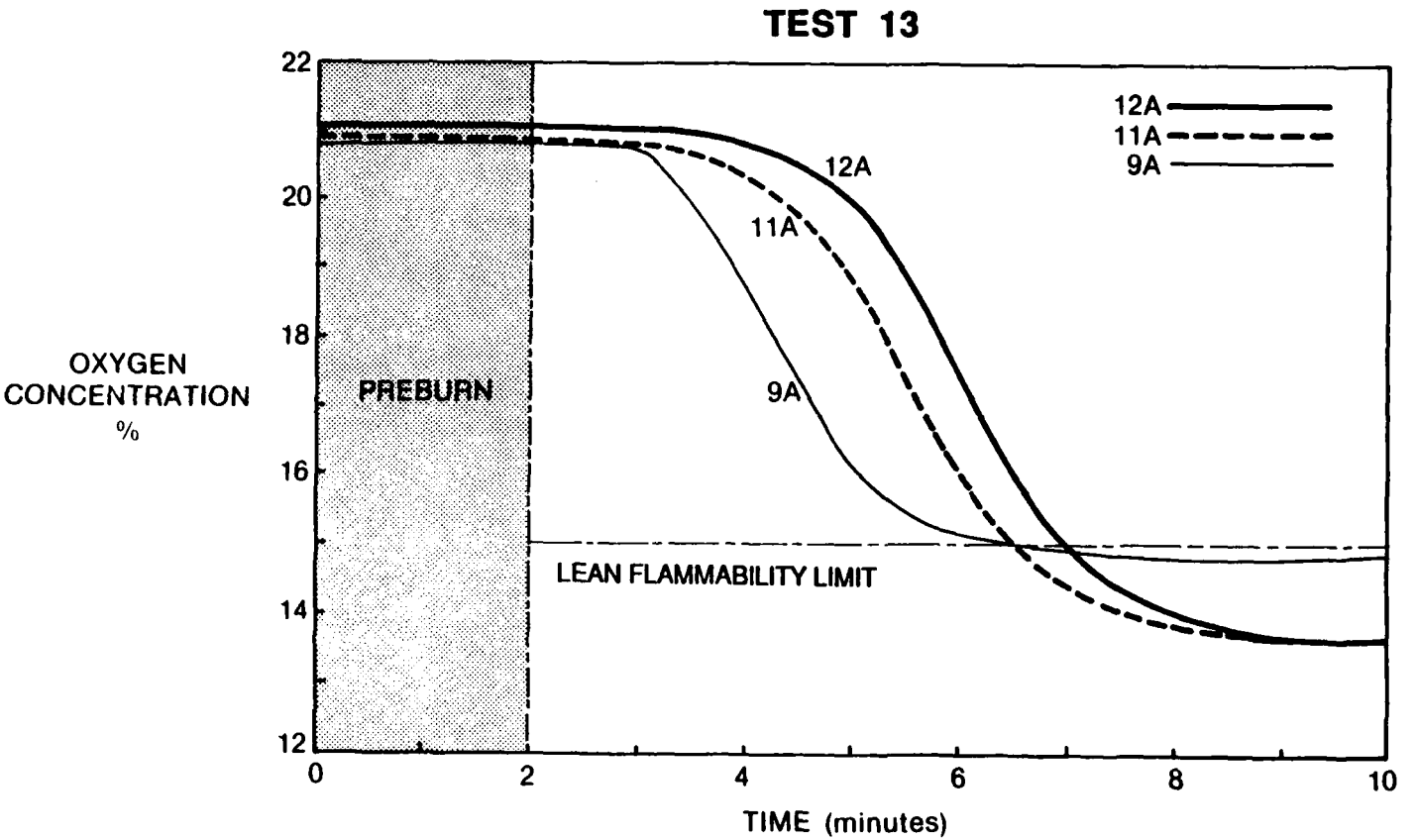


FIGURE 12a. OXYGEN CONCENTRATION TEN INCHES ABOVE DECK - USCG SINGLE DECK

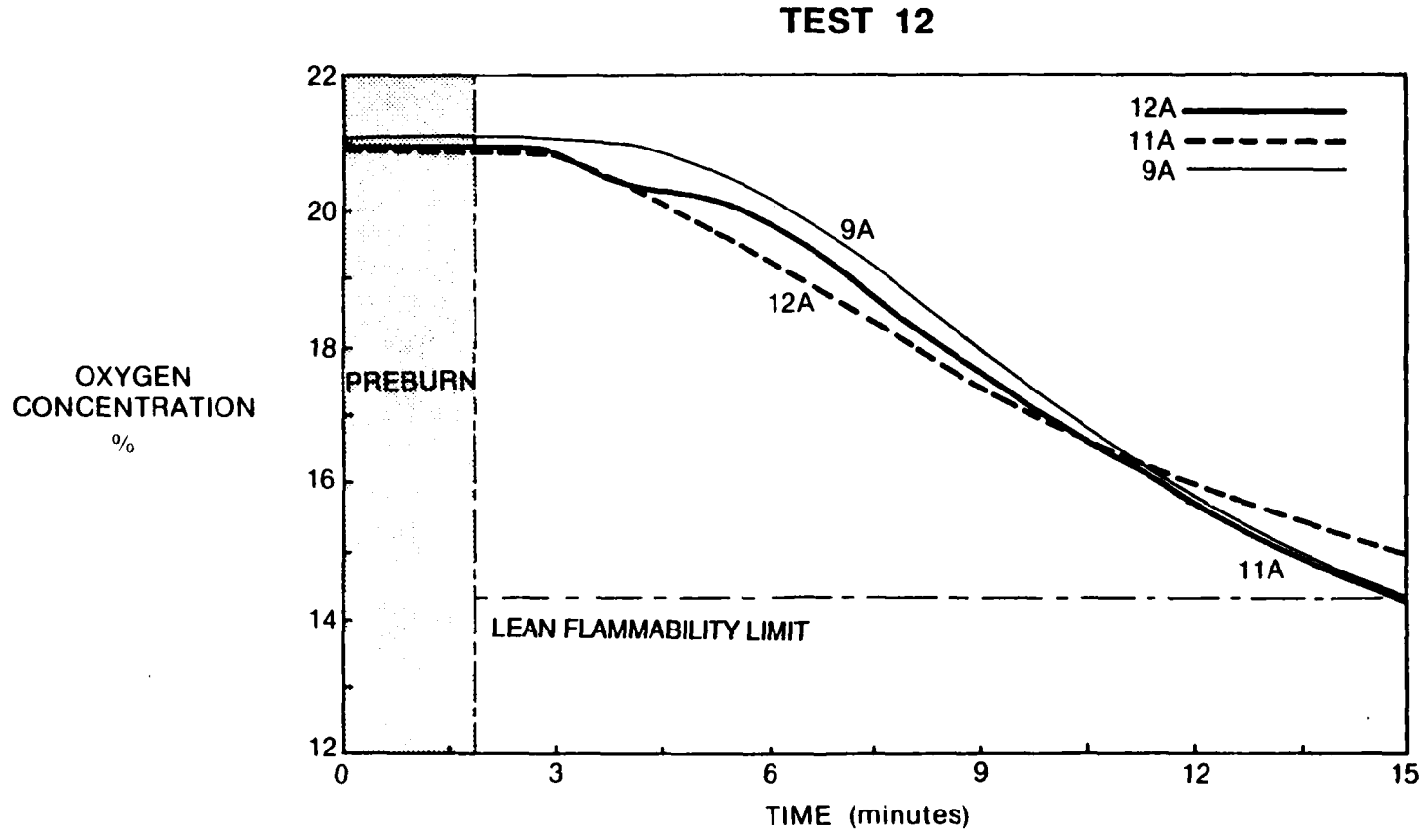


FIGURE 12b OXYGEN CONCENTRATION TEN INCHES ABOVE DECK - SOLAS SINGLE DECK

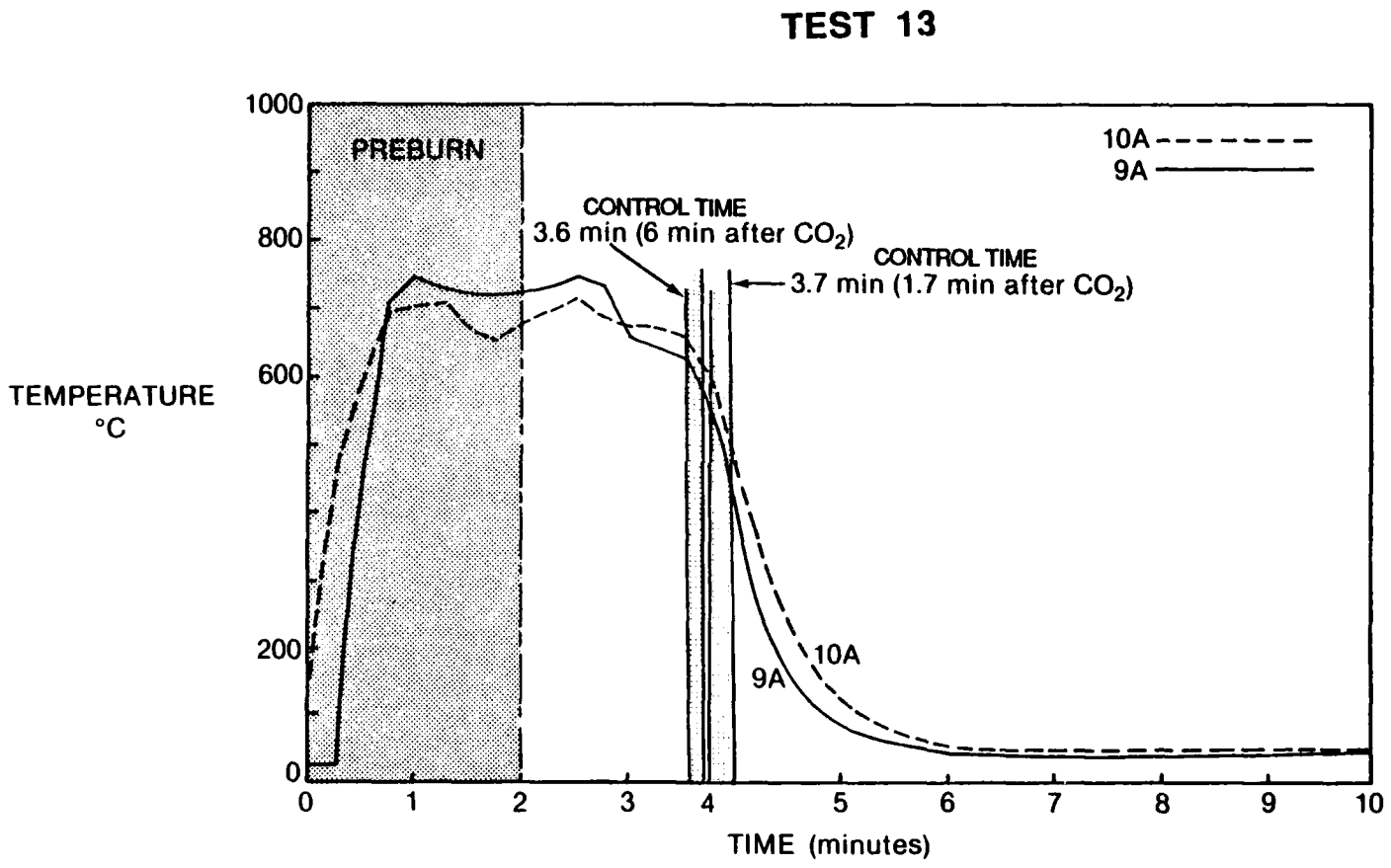


FIGURE 13a. TEMPERATURE ABOVE FIRE PANS - USCG SINGLE DECK

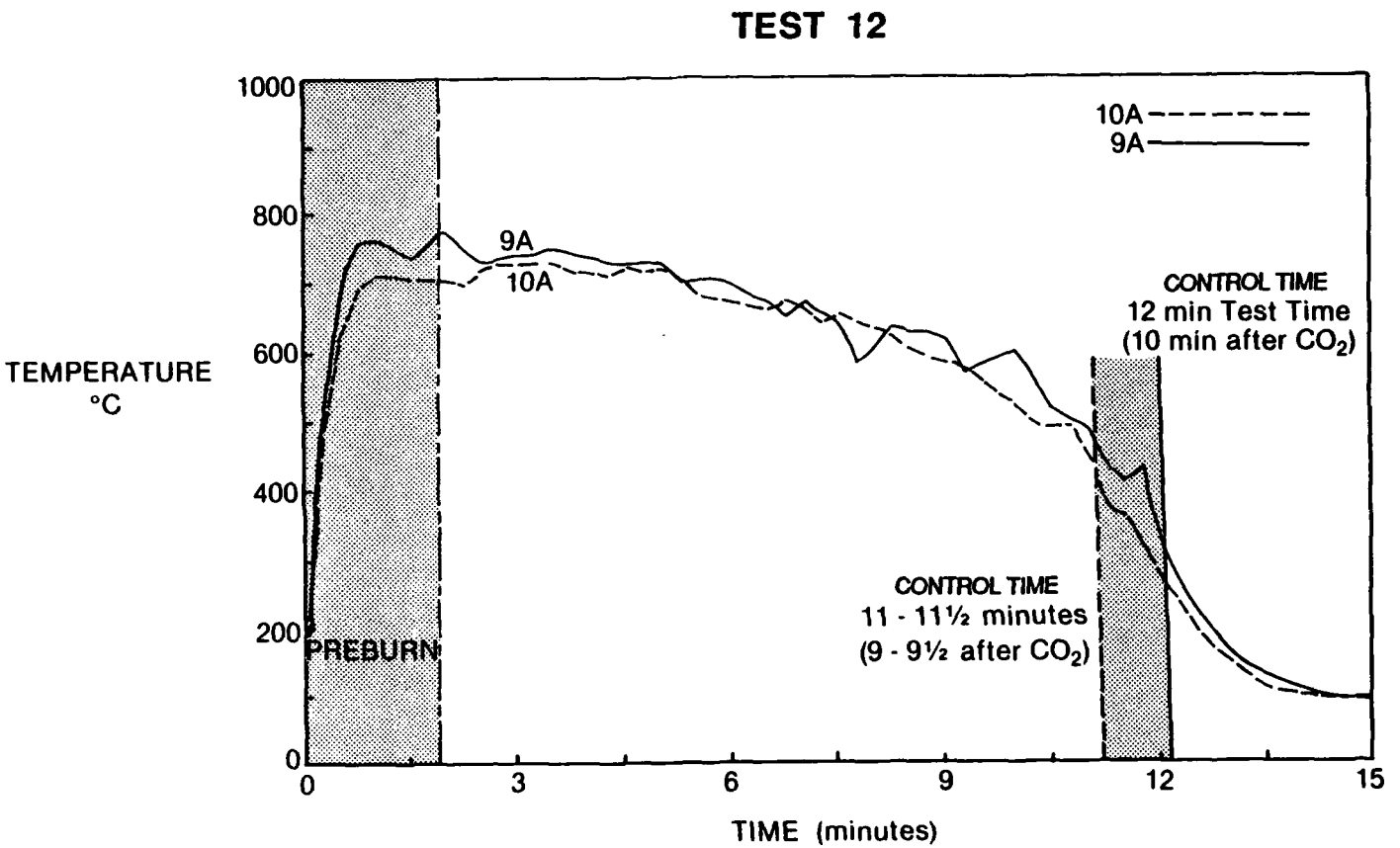


FIGURE 13b TEMPERATURE ABOVE FIRE PANS - SOLAS SINGLE DECK

during the first minute of the tests. The temperature then remains constant for a period of time ranging from 3 minutes for the USCG (Figure 13a) and 4-5 minutes for the SOLAS systems (Figure 13b). After 5 minutes the SOLAS system temperatures gradually decrease from 700°C to 500°C over a 5-6 minute time period. A similar decrease occurs for the USCG system but over a much faster time period. The control/extinction time is taken to be the point at which a "cooling" curve occurs. This cooling curve is characterized by a relatively smooth exponential decrease in temperature. For both tests this decrease starts when the temperature is in the range of the auto-ignition temperature (440-515°C) for gasoline[2]. The overall process is consistent with an initial rapid flame spread to reach a steady state equilibrium followed by a decreasing rate of combustion until a critical auto-ignition temperature is reached. For the SOLAS test the critical temperature occurs about 12 minutes into the test at which point the oxygen concentration is less than 15.5%. For the USCG tests the critical temperature occurs at about 3.8 minutes into the test. The corresponding oxygen level at this time is uncertain due to variable transit and instrumental lag times. Assuming these lag times are 2 1/2 minutes the oxygen concentration would be between 15 and 16 percent.

### 6.4 Probability of Control/Extinction

With respect to the extinguishment of the postulated flammable fuel threat, the carbon dioxide systems designed to both USCG and SOLAS standards were equally successful in extinguishing the pan fires. All fires were extinguished. Therefore it was concluded that the application rates and quantities are conservative and provide a margin of engineering safety.

### 6.5 Flow Obstruction by the "False" Decking

One of the objectives of this project was to determine whether there was a significant obstruction to flow posed by multideck construction typical of the Roll-On/Roll-Off automobile ships that had been observed. Table V contains a summary of test data. Using the SOLAS configuration the effect of the false deck can be determined by comparing Tests 11 and 12 with Tests 16 and

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[2] Fire Protection Handbook, NFPA

TABLE V
DATA SUMMARY

| Test | Fuel | Total $CO_2$ (lbs) | Rate (lbs/min) | Control Time (min) | Cu. Ft. per Pound of Carbon Dioxide* | Average % $CO_2$ at Onset of Control** | Average % $O_2$ at Onset of Control **/*** |
|---|---|---|---|---|---|---|---|
| 5 | Mineral spirits | 1115 | 87 | 14.7 | 33.5 | 20.0 | 15.9 (14.6) |
| 6 | Mineral spirits | 1122 | 91 | 13.5 | 33.3 | 21.5 | 16.3 (14.7) |
| 7 | Mineral spirits | 1470 | 490 | 7.3 | 25.4 | 22.0 | 17.4 (14.75) |
| 8 | Mineral spirits | 1475 | 421 | 7.0 | 25.3 | 23.2 | 17.4 (14.3) |
| 11 | Gasoline | 1120 | 90 | 11.7 | 33.3 | 18.3 | 16.2 (--) |
| 12 | Gasoline | 1160 | 93 | 11.3 | 32.2 | 17.6 | 16.3 (--) |
| 9 | Gasoline | 1618 | 647 | 3.7 | 23.1 | 20.7 | 19.2 (13.9) |
| 13 | Gasoline | 1620 | 810 | 3.7 | 23.0 | 20.6 | 19.6 (13.6) |
| 16 | Gasoline | 1125 | 98 | 12.8 | 33.2 | 19.7 | 16.1 (14.2) |
| 17 | Gasoline | 1128 | 97 | 12.0 | 33.10 | 19.8 | 16.5 (14.1) |
| 14 | Gasoline | 1620 | 810 | 3.7 | 23.0 | 14.7 | 19.4 (13.9) |
| 15 | Gasoline | 1580 | 790 | 3.8 | 23.6 | 16.4 | 19.0 (13.9) |

* Cargo Hold Total Volume = 37,340 $ft^3$
** Average at Auto 9A and Auto 10A
*** Numbers in parentheses indicate minimum % oxygen during test at Auto 9A, Auto 10A locations

17. Although the average rate of application for the two-deck configuration was 6.5% higher for the "false" deck system, the control time was increased by 7.8%, indicating a minor obstruction to flow. The average percent $O_2$ at onset of control was the same (16.25% vs 16.3%). Using the USCG configuration the effect of the "false" deck can be estimated by comparing Tests 9 and 13 with Tests 14 and 15. For all four tests no distinction in time required for control/extinguishment was observed. Again, the average percent $O_2$ at onset of the control/extinguishment time was the same (19.4% vs 19.2%). The discrepancy for the percent $CO_2$ at onset of control is most probably a result of sample flow and instrument transit lag times. Based on these results it was concluded that the "false" deck did not have an important effect on either the fire extinguishment processes or control times for this two-deck arrangement.

### 6.6 Effect of Fuel Type

Two fuels were evaluated; mineral spirits and gasoline. For the SOLAS rate of application, the effect of fuel type can be evaluated by comparing test data for mineral spirits (Tests 5, 6) with those for gasoline (Tests 11, 12) using the single deck configuration. Control times for the mineral spirits were 22% longer. For the USCG rate of application, a comparison of Tests 7, 8, 9, and 13 indicated the observed control times for mineral spirits were 93% longer. Because of a change in nozzles the rate of application for the USCG tests were higher for gasoline which may, in part, account for the differential. These results indicate a longer control time is required for mineral spirits than for gasoline. A possible reason for this difference could be a higher radiative feedback to the liquid mineral spirit fuel surface caused by the aromatic fractions in the mineral spirits.

### 6.7 SOLAS "Worse Case" Fire Scenario

As a final "proof" test the fire scenario was modified to determine if the rate of application of $CO_2$ prescribed by SOLAS regulations was sufficient to extinguish a very severe automobile fire. The modification consisted of saturating with gasoline the interior upholstery of the two

automobiles located above the fire pans (immediately before ignition). The resulting fire consisted of a combination of an accelerated Class A fire combined with a Class B spill fire. Since only limited instrumentation was used, the data for this test (Test 18) are not reported. After a 2-minute preburn, carbon dioxide was applied at the SOLAS rate. The fire did not propagate to adjacent automobiles. Both the Class A and Class B fires were extinguished. A post-test examination showed 1-1/2 inches of gasoline remained in each fuel pan. Only a limited quantity of Class A material remained unburned inside the automobile. Figure 14 shows the post-test condition of the two automobiles. These "worst case" test results provided a demonstration of the effectiveness of the SOLAS regulations as applied to a cargo hold containing closely spaced automobiles.

## 7.0 CONCLUSIONS

1. The application rates prescribed by SOLAS regulations are sufficient to extinguish two 5-gallon gasoline spill fires on a Roll-On/Roll-Off automobile carrier.

2. The application rates prescribed by USCG regulations are sufficient to extinguish two 5-gallon gasoline spill fires on a Roll-On/Roll-Off automobile carrier.

3. Class B spill fires (gasoline or mineral spirits) on an automobile Roll-On/Roll-Off ship can be extinguished by carbon dioxide applied at an application rate of one pound per 33 cubic feet over a 10-minute period.

4. The flow of carbon dioxide to lower levels was not significantly impeded by the simulated two-deck construction.

5. A longer time is required for control/extinguishment of mineral spirits fires than for gasoline fires.

FIGURE 14. POST TEST CONDITION OF WORST CASE AUTOMOBILES

## APPENDIX A

## ASSIGNED INSTRUMENTATION CHANNELS

| CHN# | INSTRUMENT/PARAMETER | SERIAL | RANGE | LOCATION | REMARKS |
|---|---|---|---|---|---|
| 0 | LOAD CELL CARDOX TANK | --- | 26,000# | --- | TOTAL WT 0-.1V |
| 1 | UNASSIGNED | --- | --- | --- | --- |
| 2 | LASER #1 | #370 | 0-100% | (15,20,4'8") | 0--.1V |
| 3 | LASER #2 | #366 | 0-100% | (15,40,4'8") | 0--.1V |
| 4 | LASER #3 | #359 | 0-100% | (50,20,4'8") | 0--.1V |
| 5 | LASER #4 | #378 | 0-100% | (50,40,4'8") | 0--.1V |
| 6 | LASER #5 | --- | 0-100% | (40,0-,4') | 0--.1V |
| 7 | LASER #6 | #266 | 0-100% | (40,0-,7') | 0--.1V |
| 8 | 02 GAS #1 Beckman755 | --- | 0-25% | AUTO 9 A | 0-1 |
| 9 | 02 GAS #2 Beckman755 | --- | 0-25% | AUTO 10 A | 0-1 |
| 10 | 02 GAS #3 Beckman755 | --- | 0-25% | AUTO 12 A | 0-1 |
| 11 | 02 GAS #4 L&N 7803-6 | #74-50059-1-2 | 0-25% | AUTO 11 A | 0--.005V |
| 12 | 02 GAS #5 L&N 7803-6 | #73-69702-1-1 | 0-25% | AUTO 9 B | 0--.005V |
| 13 | 02 GAS #6 L&N 7803-6 | #74-50059-1-1 | 0-25% | AUTO 12 B | 0--.005V |
| 14 | WIND VELOCITY | | 0-100 MPH | --- | 0-.1 |
| 15 | WIND DIRECTION | | 0-360° | 0° = True North | 0-.1 |

| CHN# | INSTRUMENT/PARAMETER | SERIAL | RANGE | LOCATION | REMARKS |
|---|---|---|---|---|---|
| 16 | CO2 LINE PRESSURE | --- | 0-500psi | NOZZLE #1 | 0-5V |
| 17 | CO2 LINE PRESSURE | --- | 0-500psi | NOZZLE #2 | 0-5V |
| 18 | CO2 LINE PRESSURE | --- | 0-500psi | NOZZLE #3 | 0-5V |
| 19 | CO2 LINE PRESSURE | --- | 0-500psi | NOZZLE #4 | 0-5V |
| 20 | CO2 LINE PRESSURE | --- | 0-500psi | BRANCH #1 | 0-5V |
| 21 | CO2 LINE PRESSURE | --- | 0-500psi | BRANCH #2 | 0-5V |
| 22 | CO2 LINE PRESSURE | --- | 0-500psi | MAIN LINE | 0-5V |
| 23 | CO2 CARDOX TANK PRESSURE | --- | 0-500psi | MAIN TANK | 0-5V |
| 24 | UNASSIGNED | --- | --- | --- | --- |
| 25 | CO2 GAS #1 | MSA 34056 | 0-30% | AUTO 9 A | 0-.1 |
| 26 | CO2 GAS #2 | MSA 34057 | 0-50% | AUTO 10 A | 0-.1 |
| 27 | CO2 GAS #3 | MSA 31334 | 0-50% | AUTO 11 A | 0-.1 |
| 28 | CO2 GAS #4 | MSA 34059 | 0-50% | AUTO 12 A | 0-.1 |
| 29 | CO2 GAS #5 | MSA 34061 | 0-100% | AUTO 9 C | 0-.1 |
| 30 | CO2 GAS #6 | MSA 34062 | 0-100% | AUTO 3 A | 0-.1 |
| 31 | CO2 GAS #7 | MSA 30606 | 0-100% | AUTO 9 B | 0-.1 |
| 32 | CO2 GAS #8 | MSA 31335 | 0-100% | AUTO 12 B | 0-.1 |
| 33 | CO2 GAS #9 | MSA 34063 | 0-100% | AUTO 3 B | 0-.1 |
| 34 | CO2 GAS #10 | BECKMAN 0103496 | 0-20% | ROVING-HOLD#2 | 0-.1 |
| 35 | CO2 GAS #11 | MSA LIRA 303 #34064 | 0-25% | OBSERVATION ROOM | 0-.1 |
| 36 | CO2 GAS #12 | MSA LIRA 303 #34065 | 0-25% | BELOW FIRE DECK | 0-.1 |

| CHN# | INSTRUMENT/PARAMETER | SERIAL | RANGE | LOCATION | REMARKS |
|---|---|---|---|---|---|
| 37 | T/C #1 Type K | -- | 0-1000C | AUTO 14 A | --- |
| 38 | T/C #2 Type K | -- | 0-1000C | AUTO 14 B | --- |
| 39 | T/C #3 Type K | -- | 0-1000C | AUTO 14 C | --- |
| 40 | T/C #4 Type K | -- | 0-1000C | AUTO 15 A | --- |
| 41 | T/C #5 Type K | -- | 0-1000C | AUTO 15 B | --- |
| 42 | T/C #6 Type K | -- | 0-1000C | AUTO 15 C | --- |
| 43 | T/C #7 Type K | -- | 0-1000C | AUTO 16 A | --- |
| 44 | T/C #8 Type K | -- | 0-1000C | AUTO 16 B | --- |
| 45 | T/C #9 Type K | -- | 0-1000C | AUTO 16 C | --- |
| 46 | T/C #10 Type K | -- | 0-1000C | UNASSIGNED | --- |
| 47 | T/C #11 Type K | -- | 0-1000C | AUTO 8 A | --- |
| 48 | T/C #12 Type K | -- | 0-1000C | AUTO 8 B | --- |
| 49 | T/C #13 Type K | -- | 0-1000C | AUTO 8 C | --- |
| 50 | T/C #14 Type K | -- | 0-1000C | AUTO 9 A | --- |
| 51 | T/C #15 Type K | -- | 0-1000C | AUTO 9 B | --- |
| 52 | T/C #16 Type K | -- | 0-1000C | AUTO 9 C | --- |
| 53 | T/C #17 Type K | -- | 0-1000C | AUTO 10 A | --- |
| 54 | T/C #18 Type K | -- | 0-1000C | AUTO 10 B | --- |
| 55 | T/C #19 Type K | -- | 0-1000C | AUTO 10 C | --- |
| 56 | T/C #20 Type K | -- | UNASSIGNED | | --- |
| 57 | T/C #21 Type K | -- | 0-1000C | AUTO 11 A | --- |
| 58 | T/C #22 Type K | -- | 0-1000C | AUTO 11 B | --- |
| 59 | T/C #23 Type K | -- | 0-1000C | AUTO 11 C | --- |
| 60 | T/C #24 Type K | -- | 0-1000C | AUTO 12 A | --- |
| 61 | T/C #25 Type K | -- | 0-1000C | AUTO 12 B | --- |
| 62 | T/C #26 Type K | -- | 0-1000C | AUTO 12 C | --- |

| CHN# | INSTRUMENT/PARAMETER | | SERIAL | RANGE | LOCATION | REMARKS |
|---|---|---|---|---|---|---|
| 63 | T/C #27 | Type K | -- | 0-1000C | AUTO 2 A | --- |
| 64 | T/C #28 | Type K | -- | 0-1000C | AUTO 2 B | --- |
| 65 | T/C #29 | Type K | -- | 0-1000C | AUTO 2 C | --- |
| 66 | T/C #30 | Type K | -- | UNASSIGNED | | --- |
| 67 | T/C #31 | Type K | -- | 0-1000C | AUTO 3 A | --- |
| 68 | T/C #32 | Type K | -- | 0-1000C | AUTO 3 B | --- |
| 69 | T/C #33 | Type K | -- | 0-1000C | AUTO 3 C | --- |
| 70 | T/C #34 | Type K | -- | 0-1000C | AUTO 4 A | --- |
| 71 | T/C #35 | Type K | -- | 0-1000C | AUTO 4 B | --- |
| 72 | T/C #36 | Type K | -- | 0-1000C | AUTO 4 C | --- |
| 73 | T/C #37 | Type K | -- | 0-1000C | AUTO 5 A | --- |
| 74 | T/C #38 | Type K | -- | 0-1000C | AUTO 5 B | --- |
| 75 | T/C #39 | Type K | -- | 0-1000C | AUTO 5 C | --- |
| 76 | T/C #40 | Type K | -- | UNASSIGNED | | --- |
| 77 | T/C #41 | Type K | -- | 0-1000C | AUTO 17 A | --- |
| 78 | T/C #42 | Type K | -- | 0-1000C | AUTO 17 B | --- |
| 79 | T/C #43 | Type K | -- | 0-1000C | AUTO 17 C | --- |

# APPENDIX B

## TEST 1

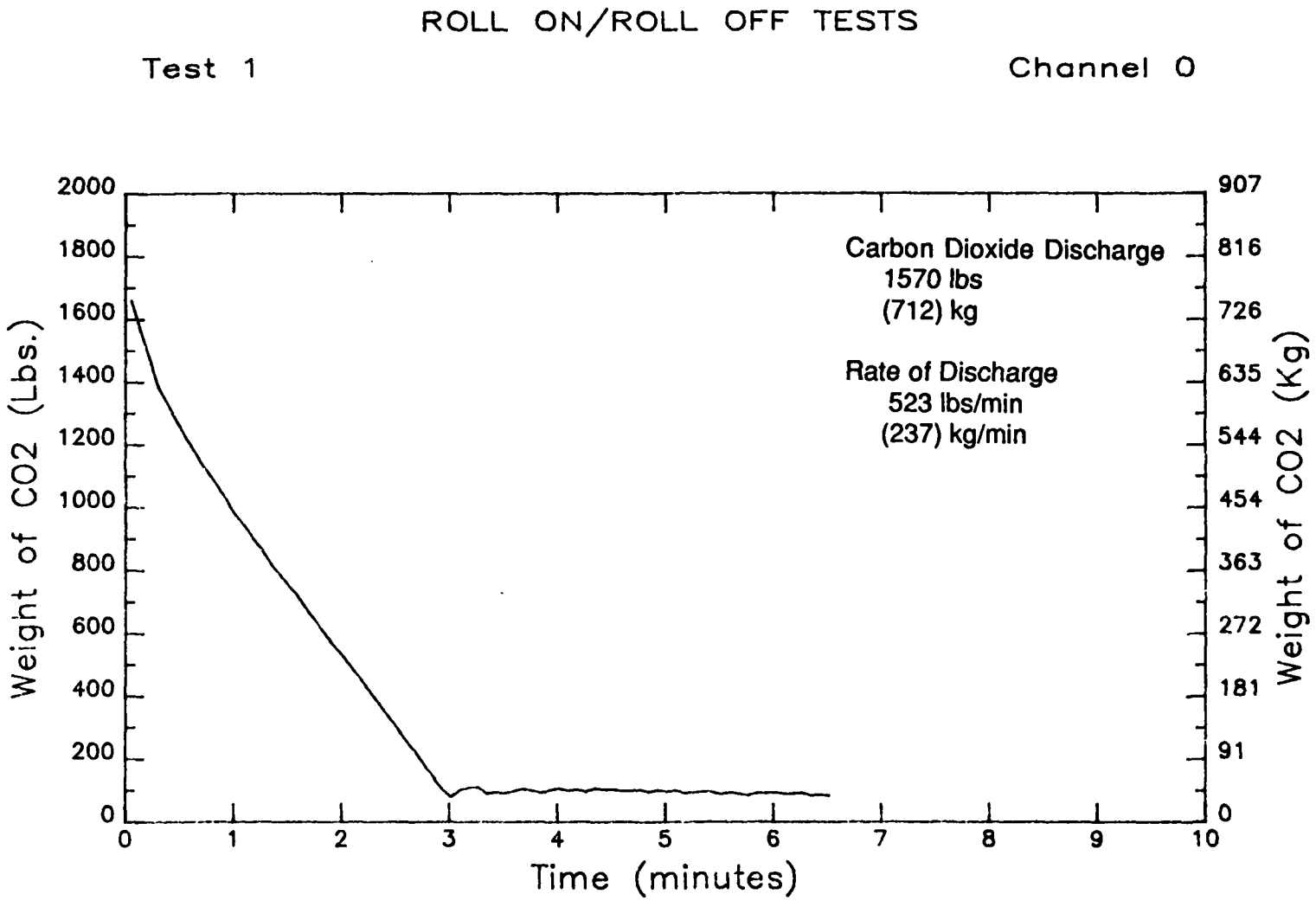
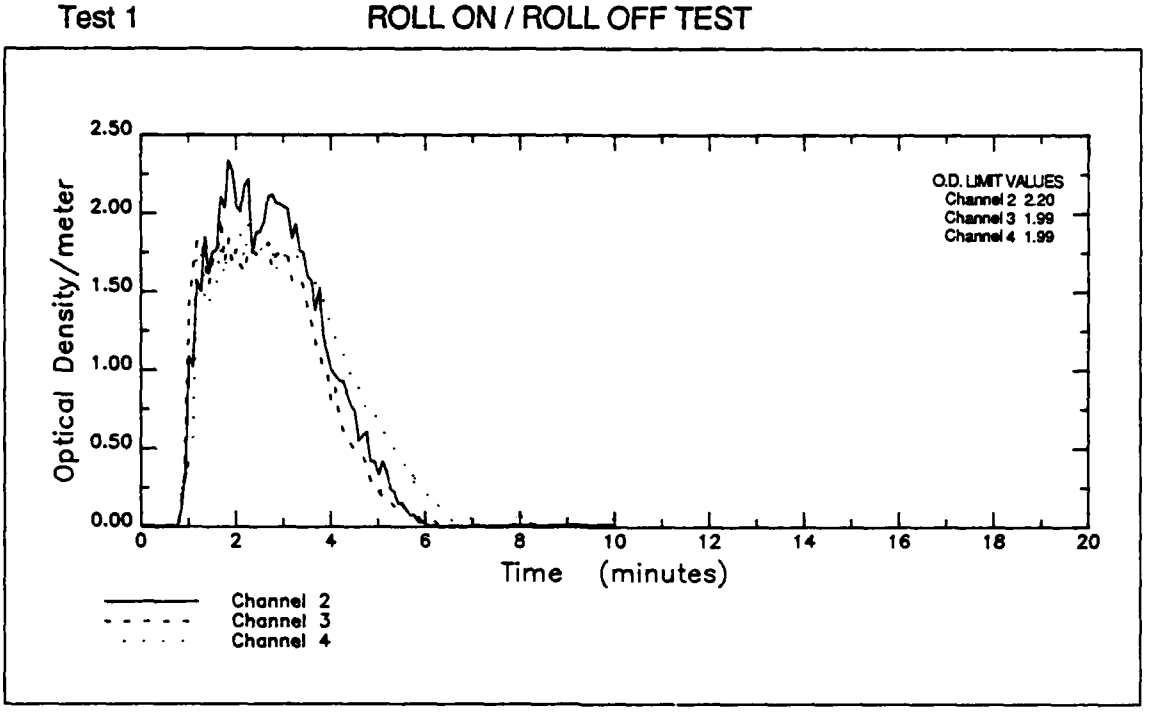
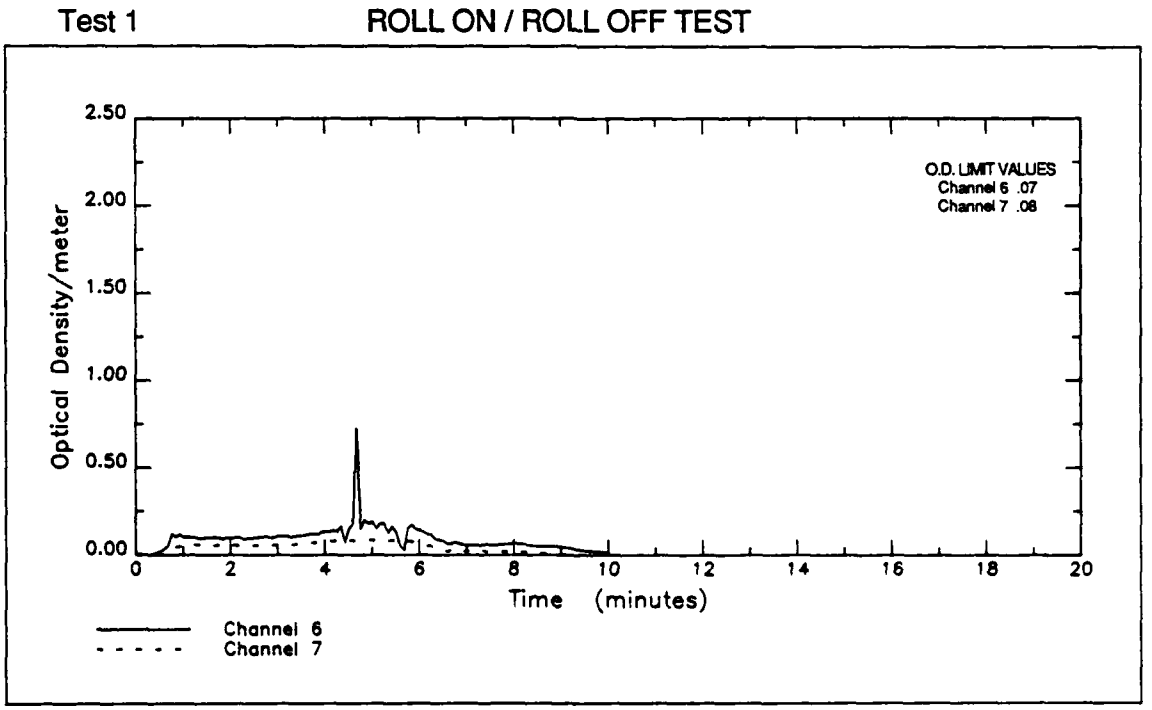



FIGURE B 1-1 Weight of Carbon Dioxide vs Time




a. Data Channels 2, 3, 4, 5




b. Data Channels 6,7

**FIGURE B 1-2. OPTICAL DENSITY vs TIME**

# APPENDIX B

# TEST 2

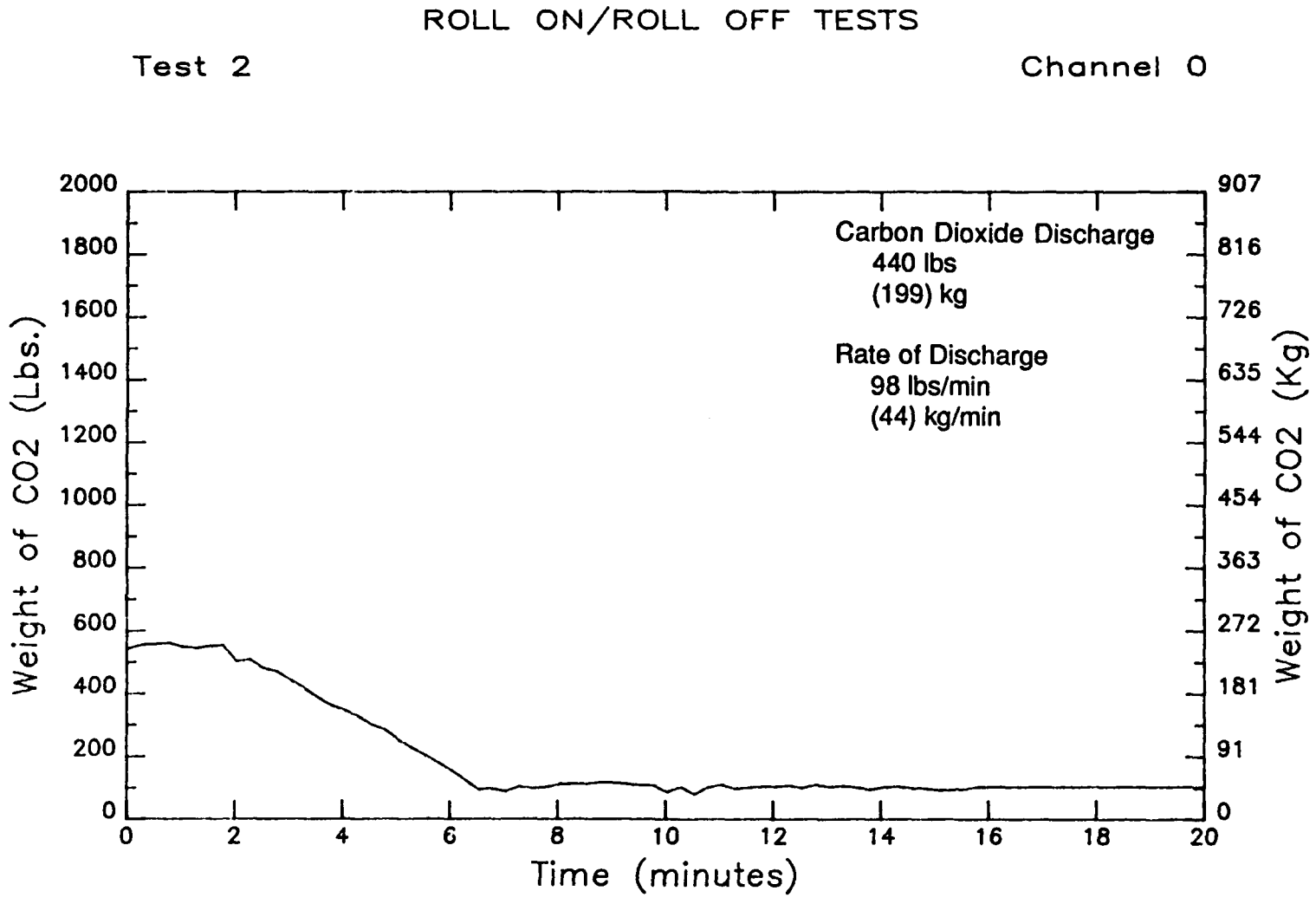
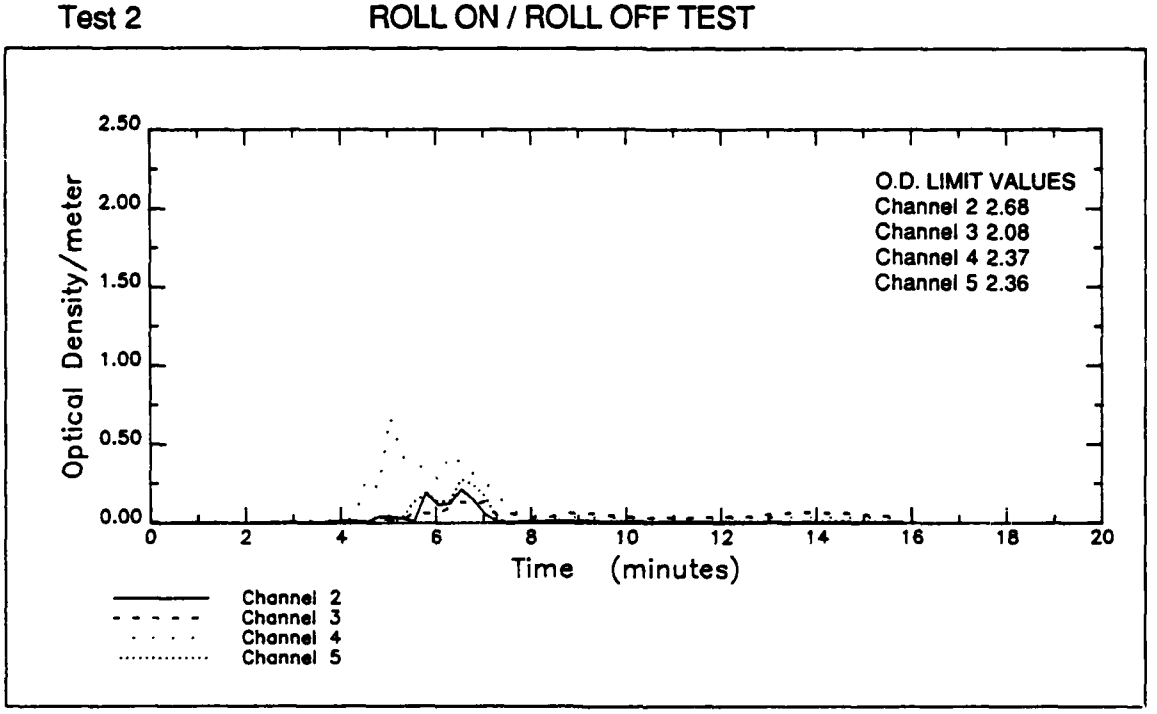
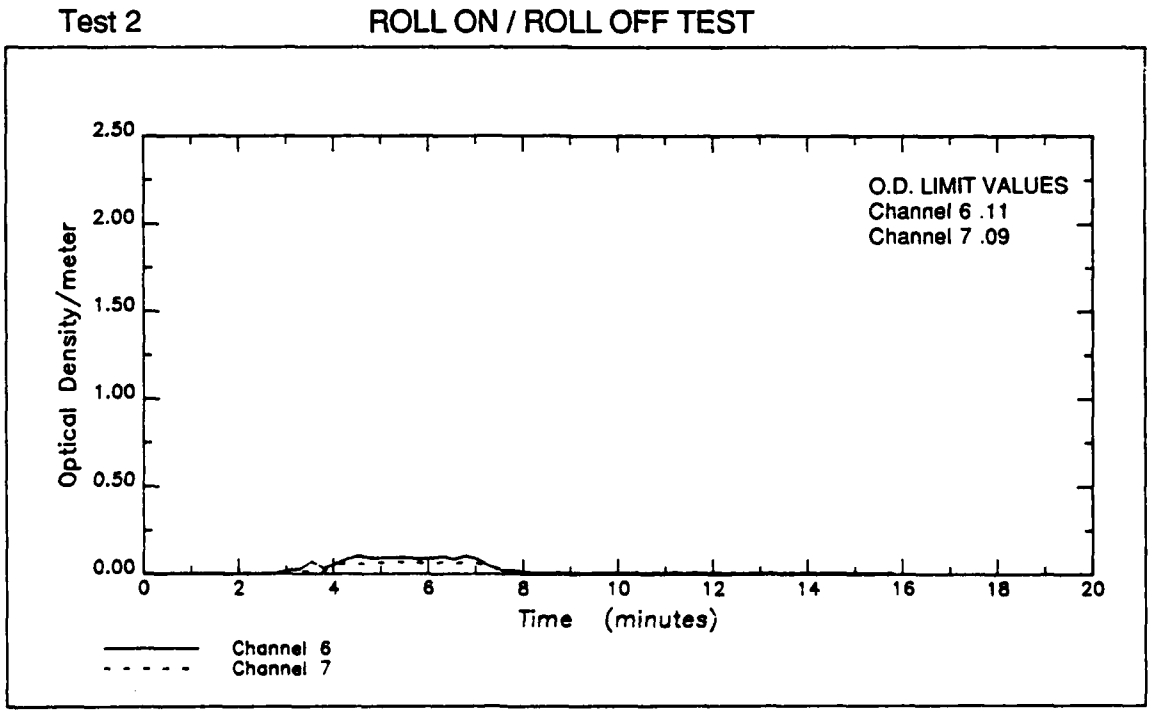



FIGURE B 2-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2, 3, 4, 5




b. Data Channels 6,7

**FIGURE B 2-2. OPTICAL DENSITY vs TIME**

# APPENDIX B

# TEST 3

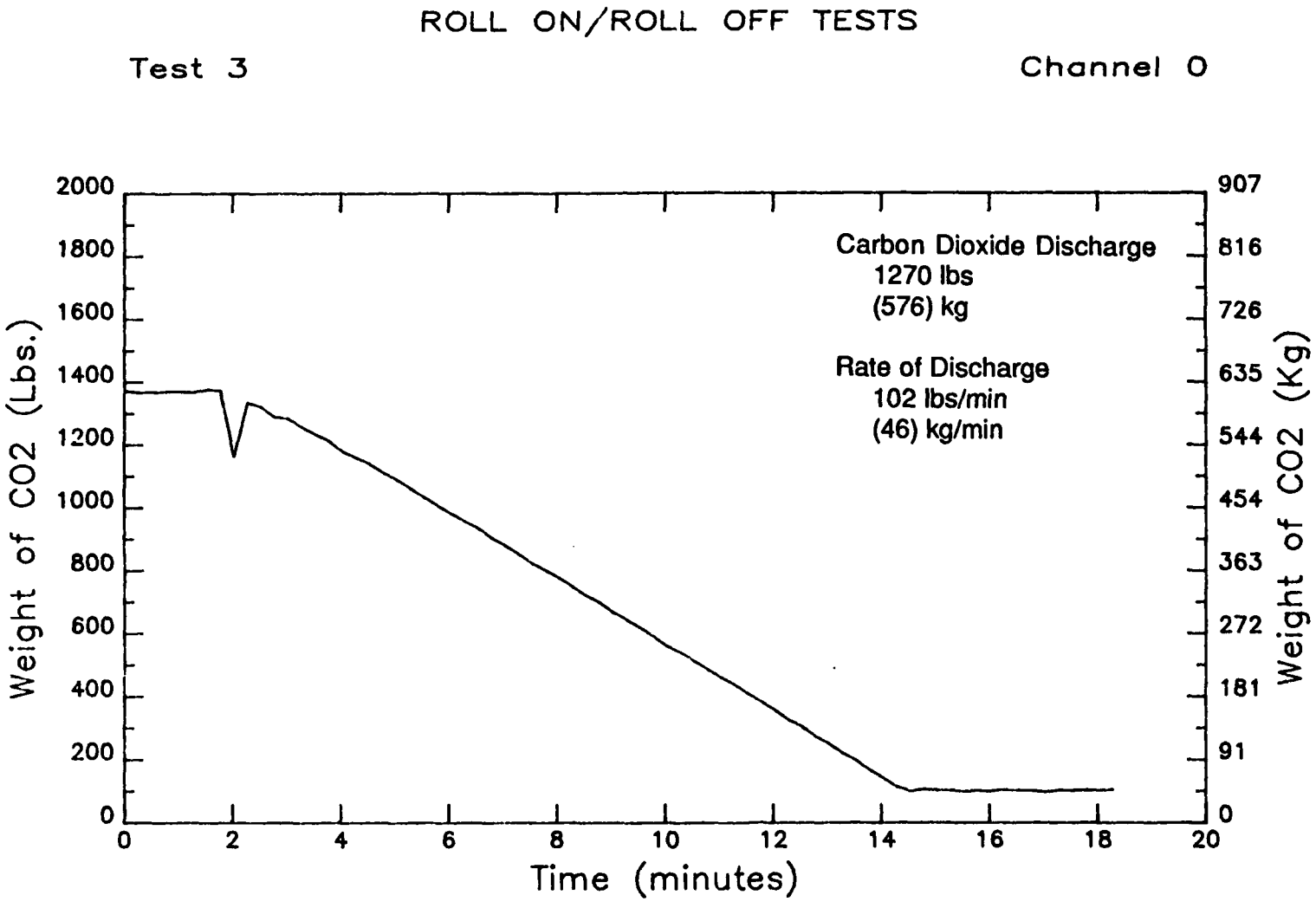
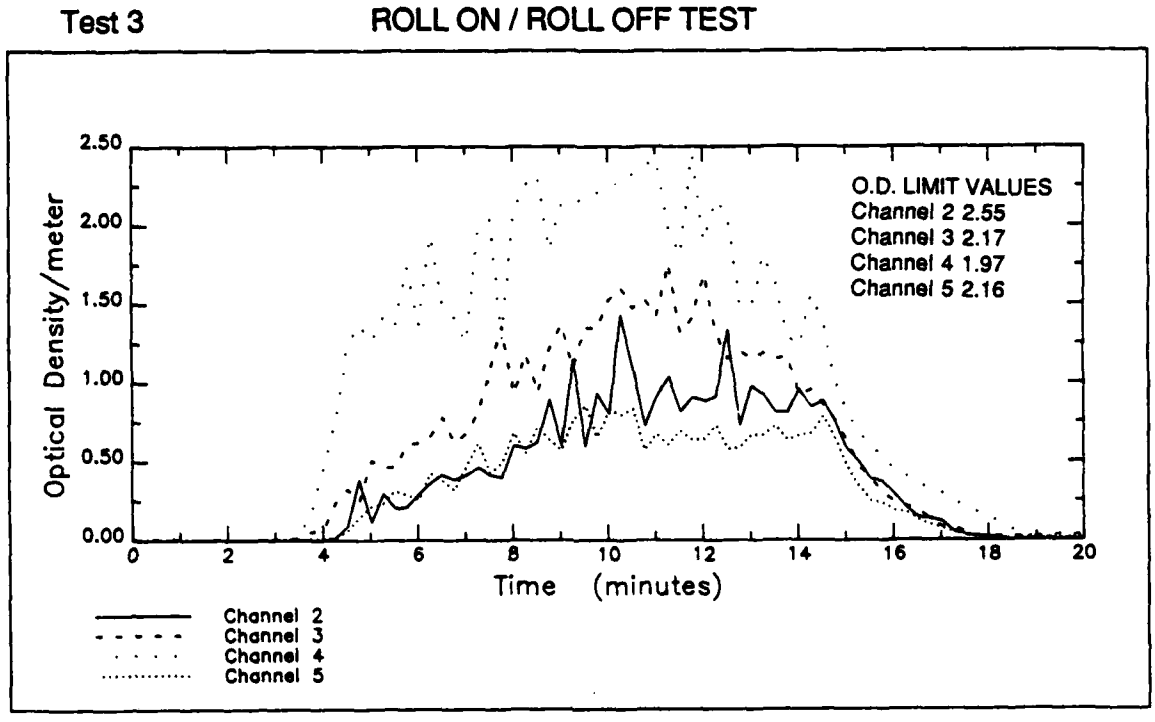
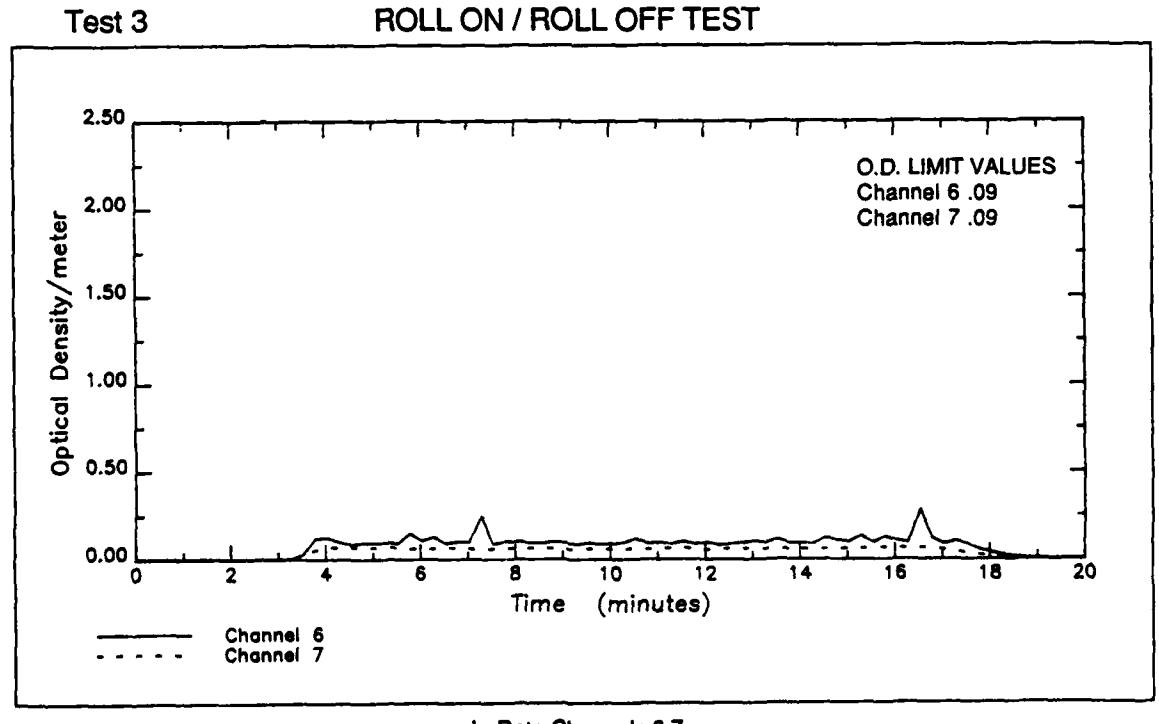



FIGURE B 3-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2, 3, 4, 5




b. Data Channels 6,7

**FIGURE B 3-2. OPTICAL DENSITY vs TIME**

# APPENDIX B

# TEST 4

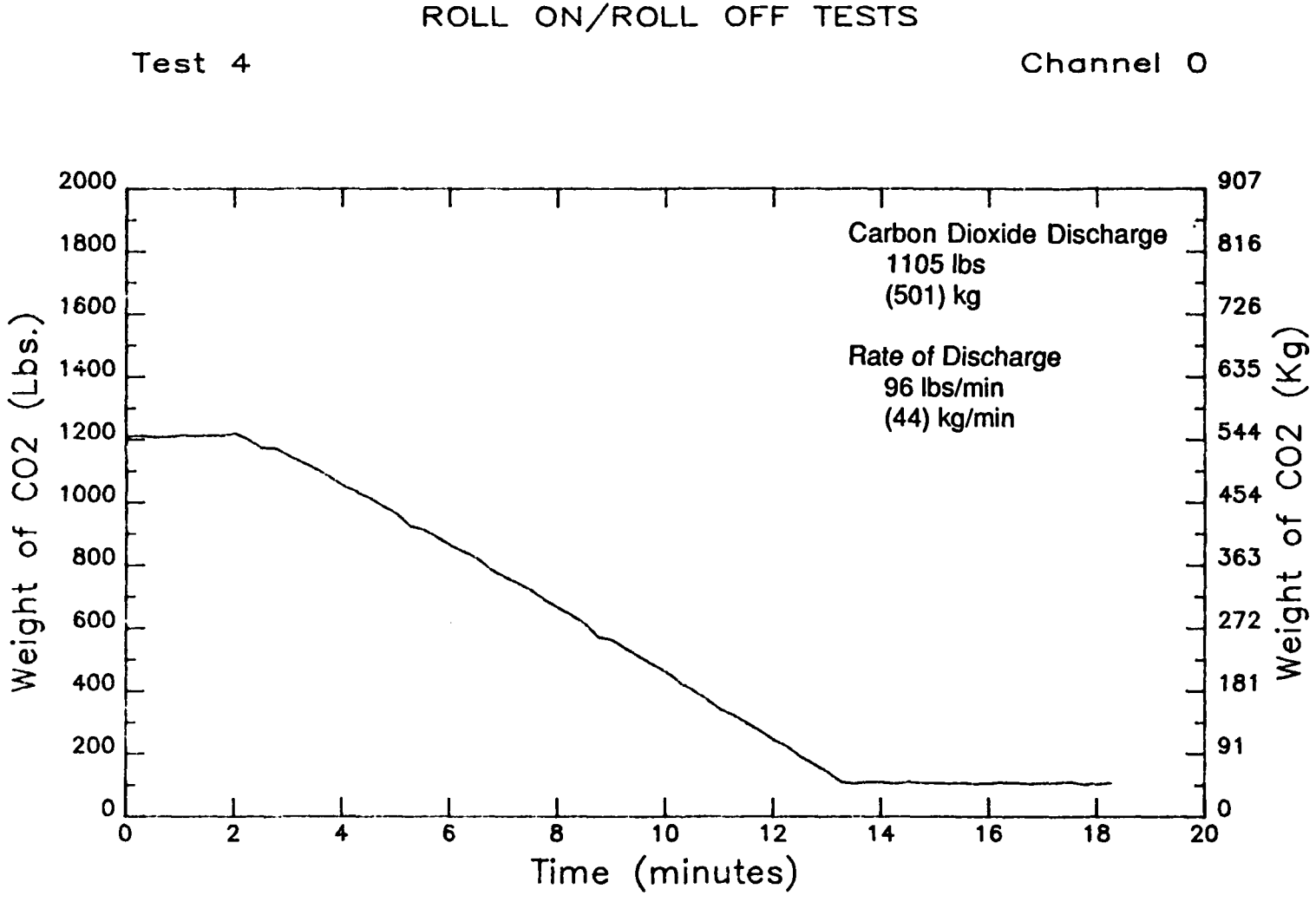
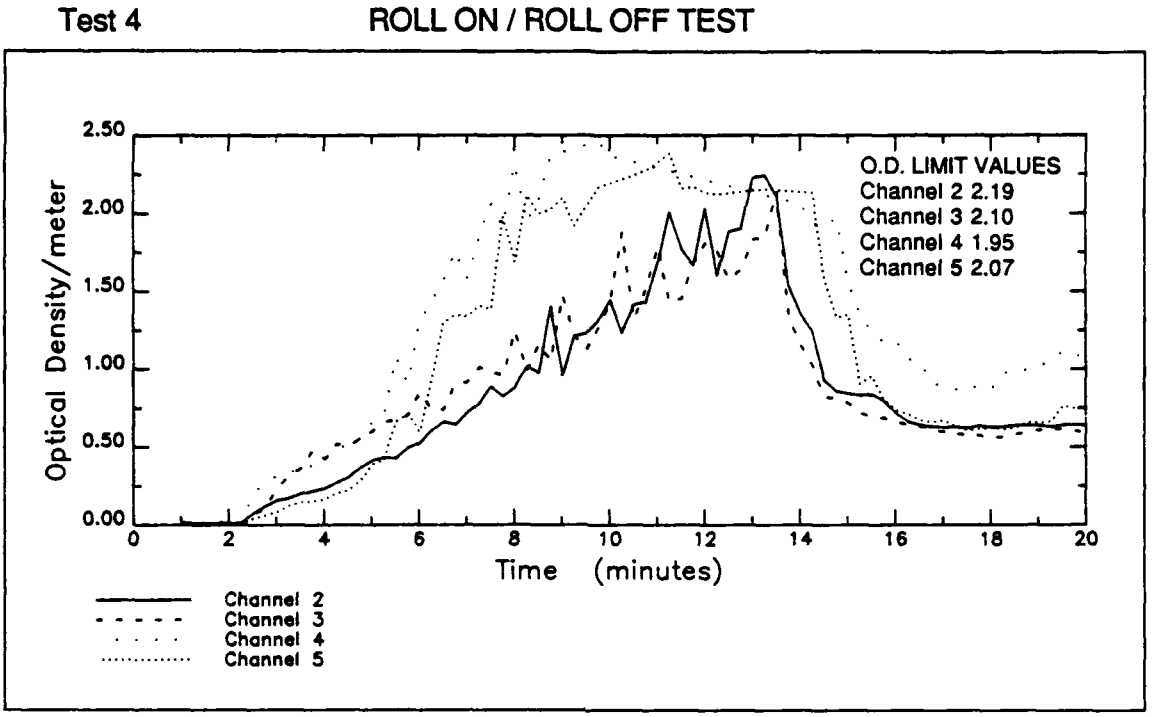
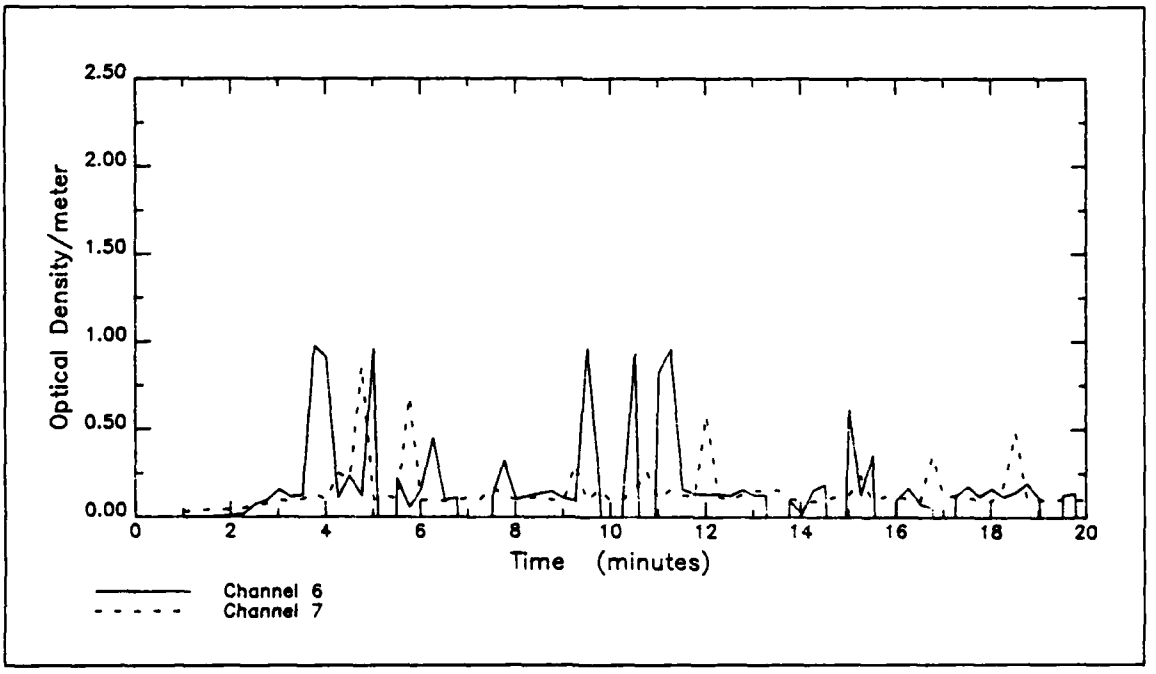



FIGURE B 4-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2, 3, 4, 5




b. Data Channels 6,7

**FIGURE B 4-2. OPTICAL DENSITY vs TIME**

# APPENDIX B

# TEST 5

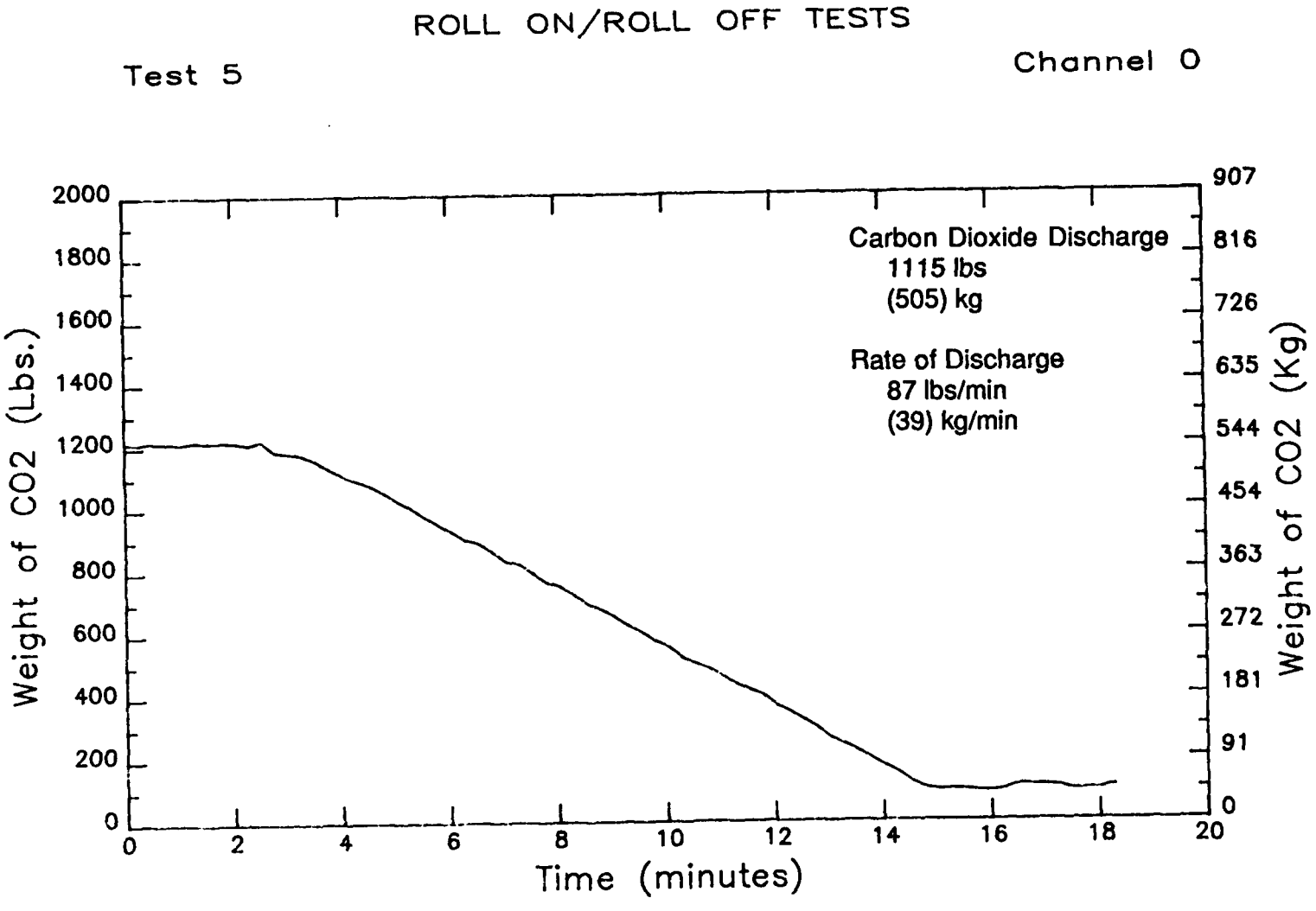



FIGURE B 5-1. Weight of Carbon Dioxide vs Time

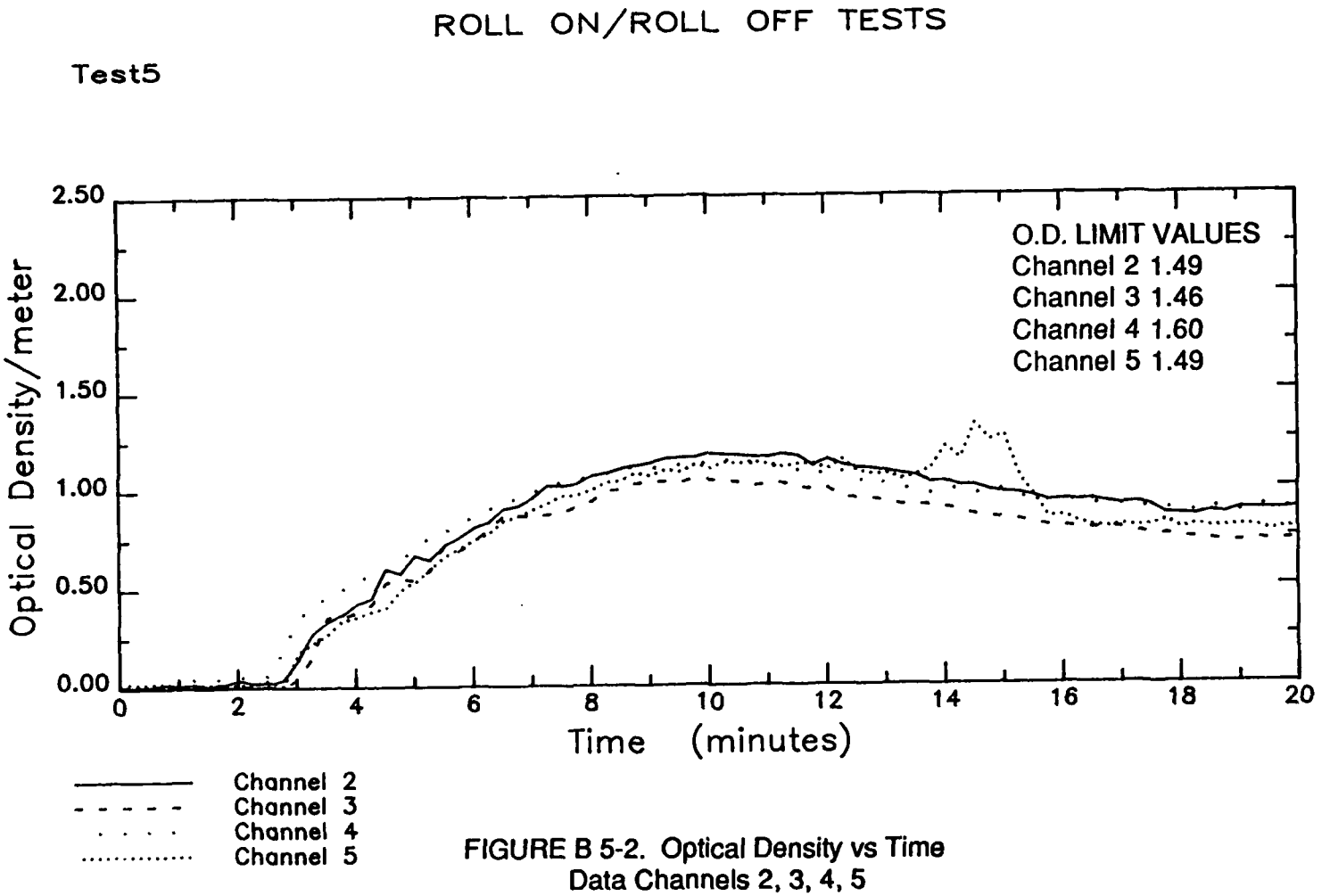



FIGURE B 5-2. Optical Density vs Time
Data Channels 2, 3, 4, 5

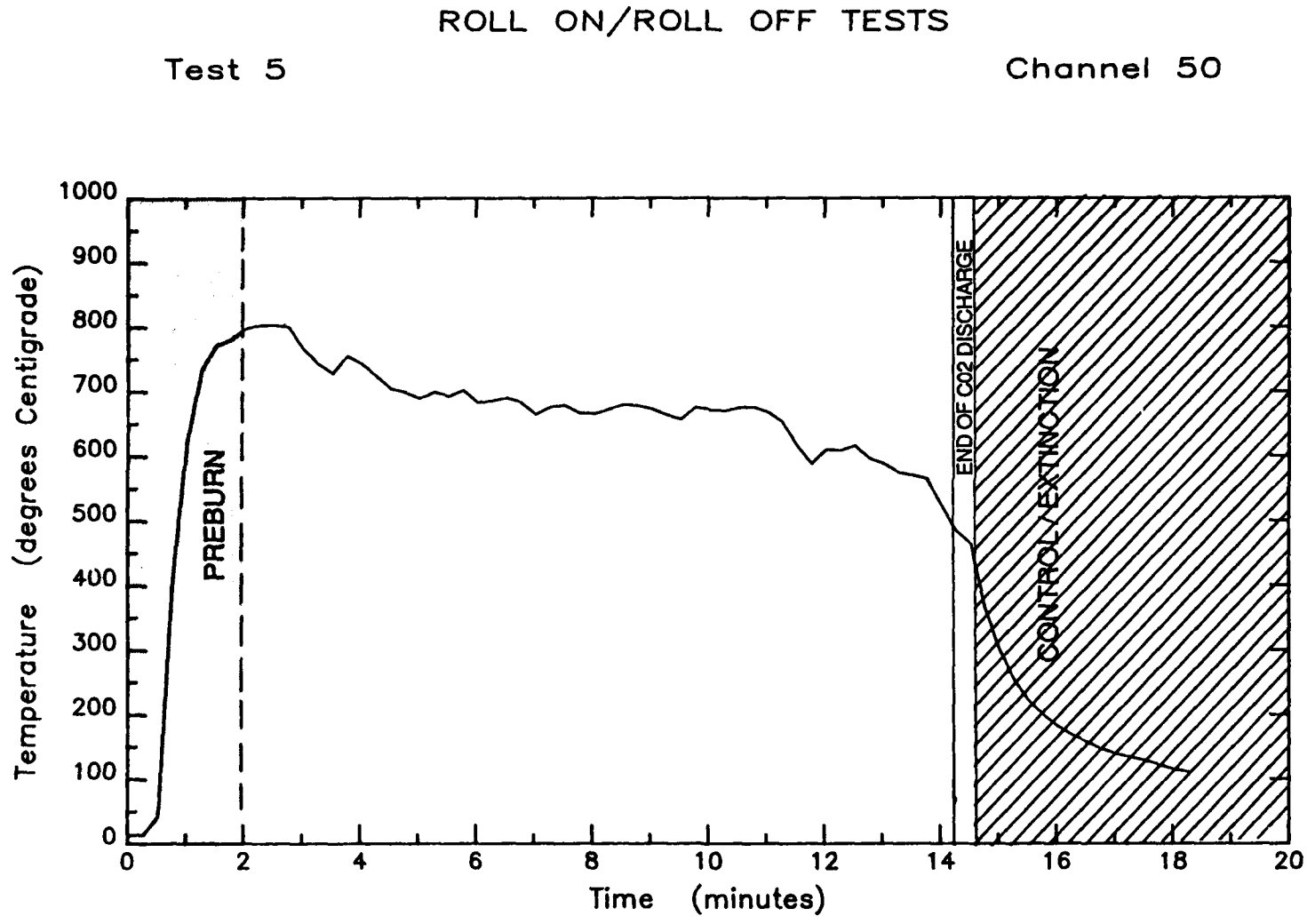



FIGURE B 5-3. Temperature vs Time - Location 9A

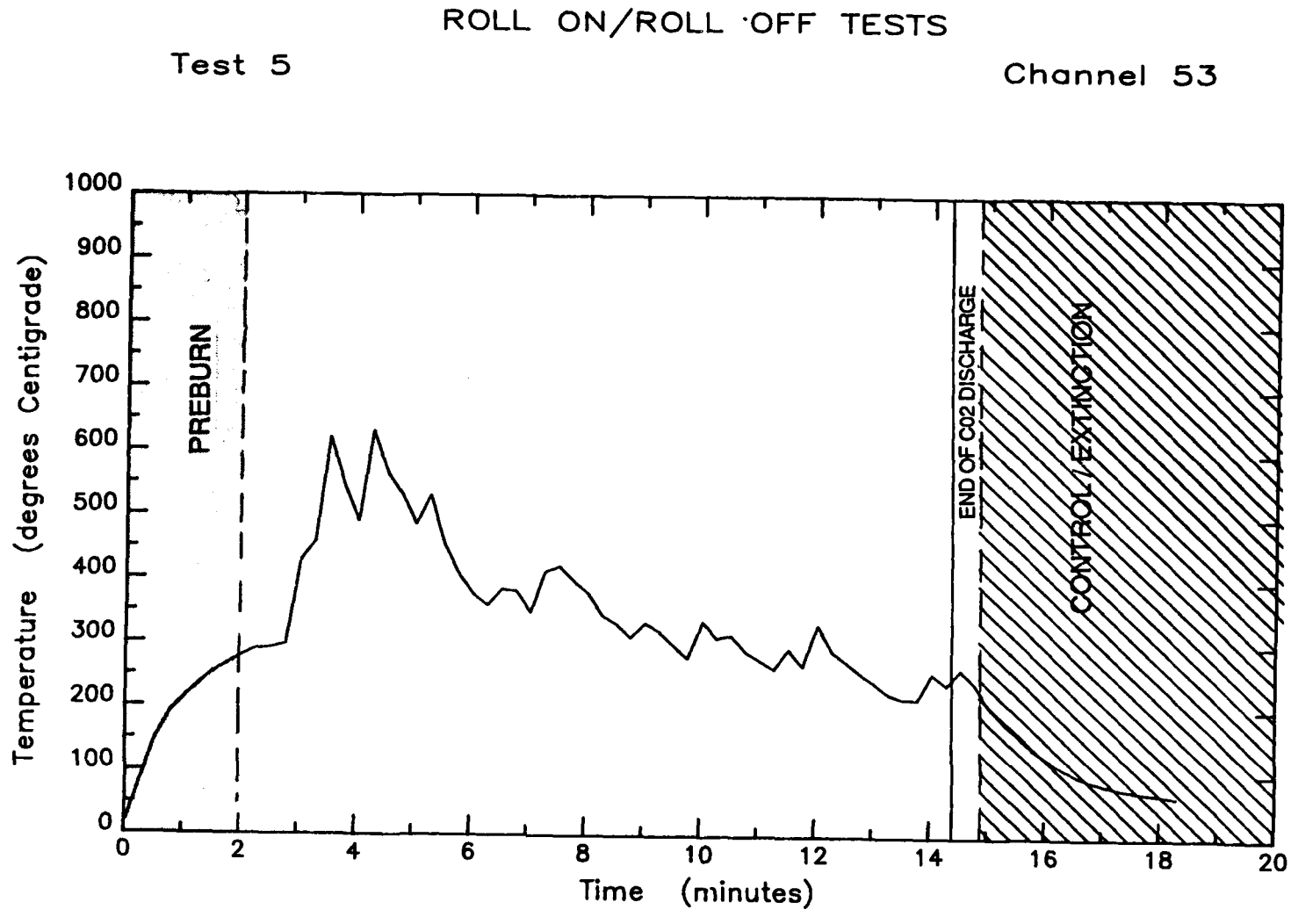
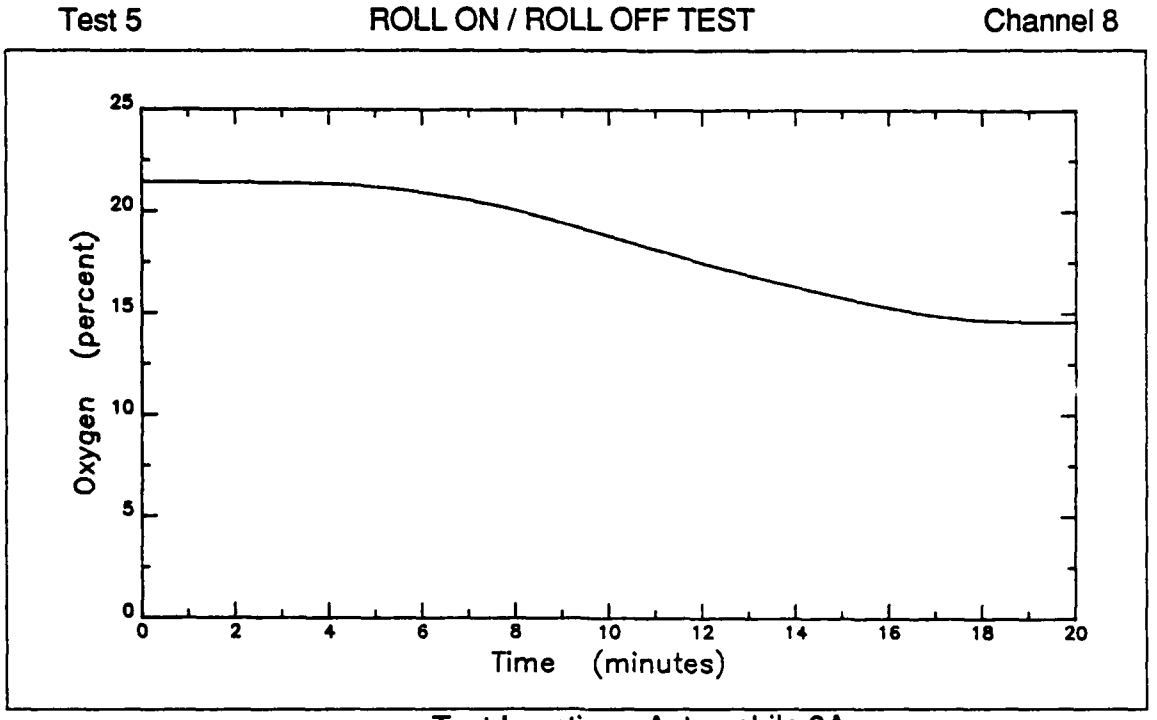



FIGURE B 5-4. Temperature vs Time - Location 10A

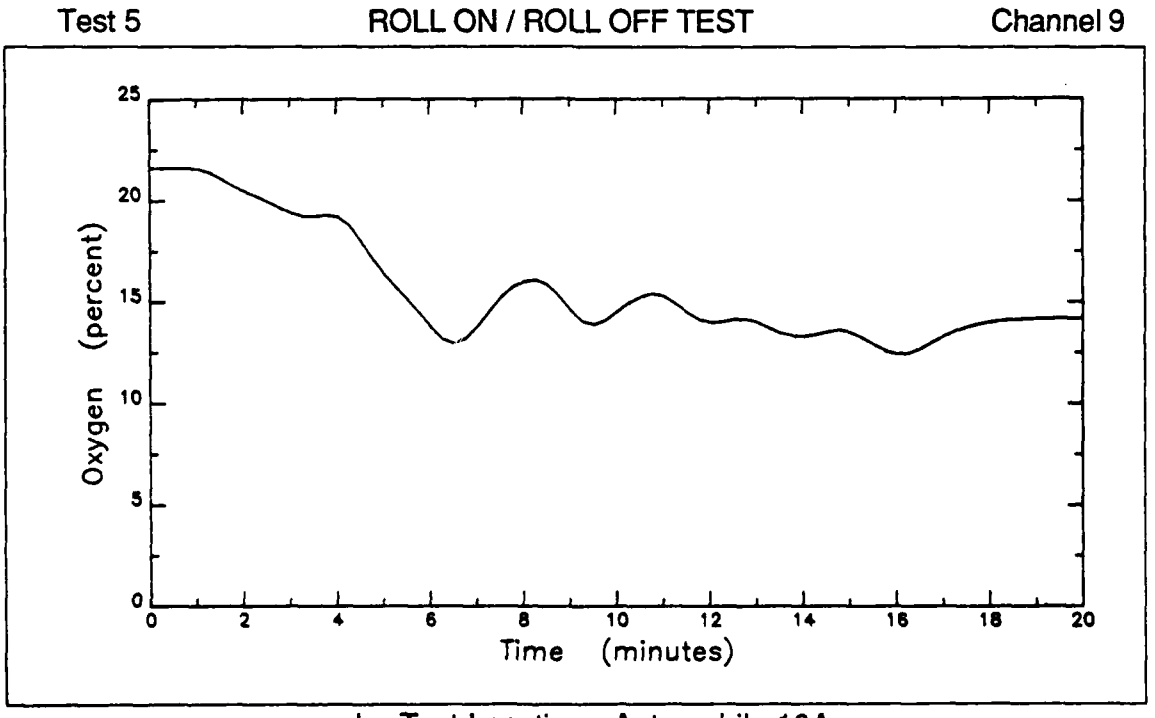
TEST 5

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 14.7 | 15.9 | 2.0 | 14.6 | |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | -- | -- | -- | -- | |
| 11 | Auto 11A | 14.7 | 16.3 | 18.3 | 15.8 | |
| 12 | Auto 9B | 14.7 | 16.0 | 16.0 | 15.6 | |
| 13 | Auto 12B | 14.7 | 17.5 | 16.5 | 17.0 | |
| | | AVERAGE | 16.4 | 16.9 | 15.7 | |

FIGURE B 5-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

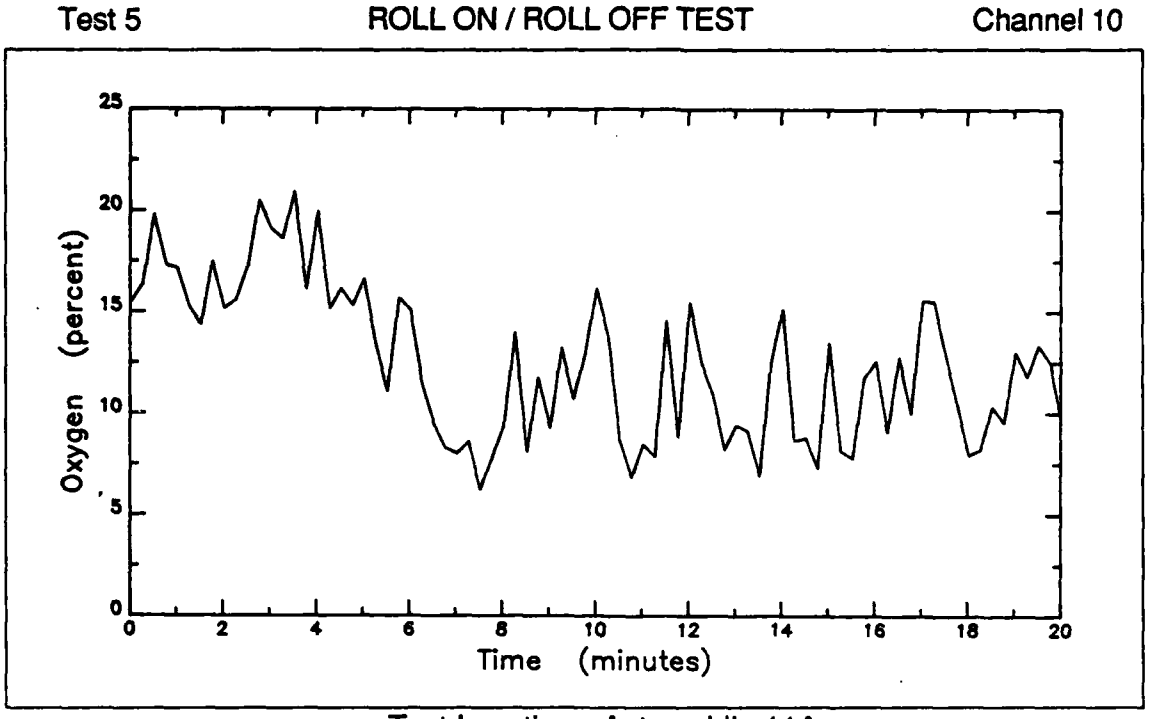



a. Test Location - Automobile 9A

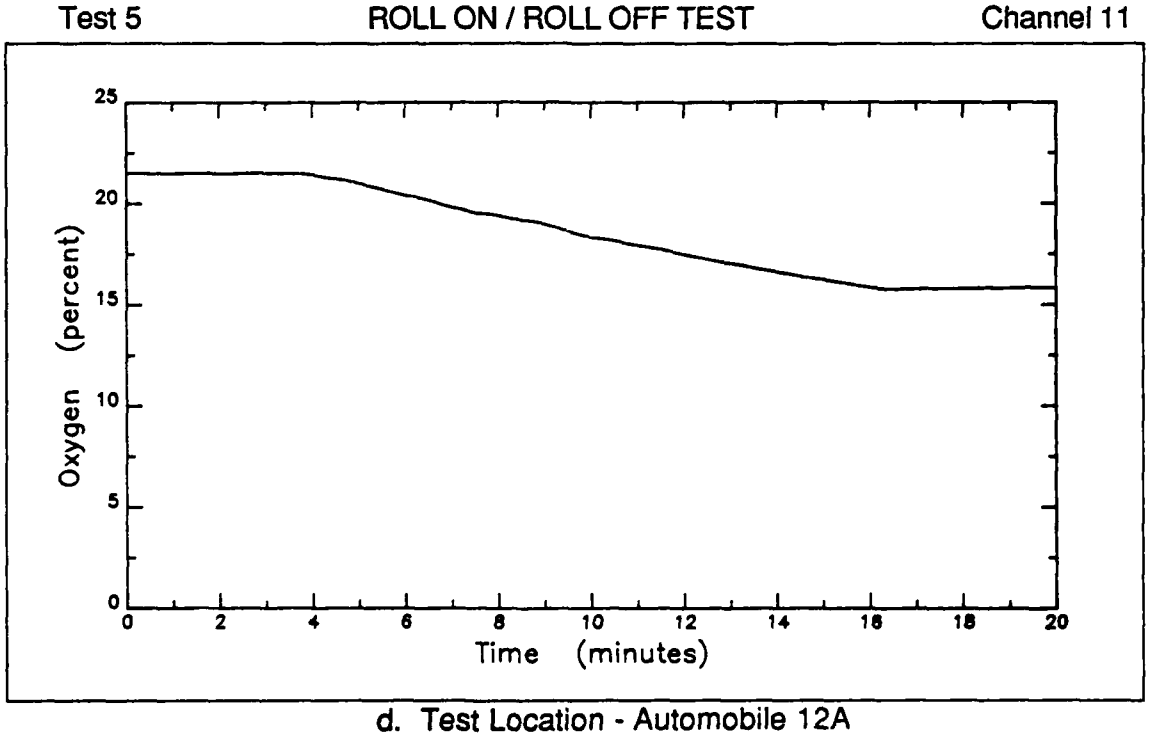



b. Test Location - Automobile 10A

**FIGURE B 5-6. PERCENT OXYGEN vs TIME**

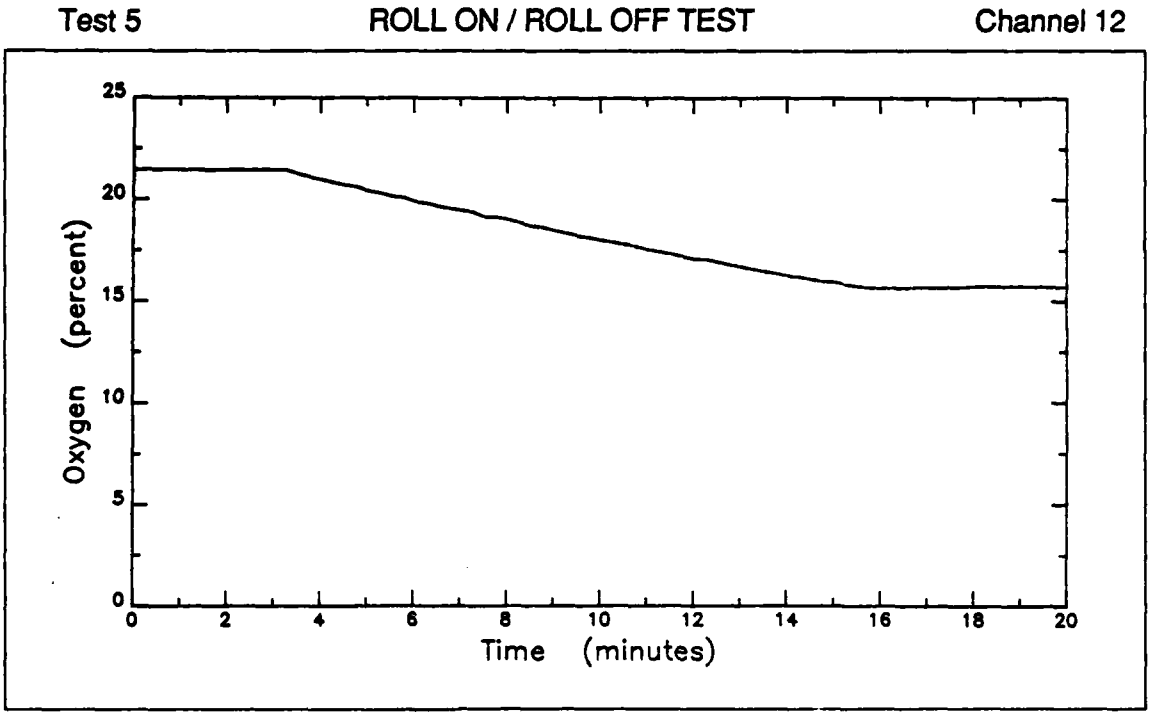



c. Test Location - Automobile 11A

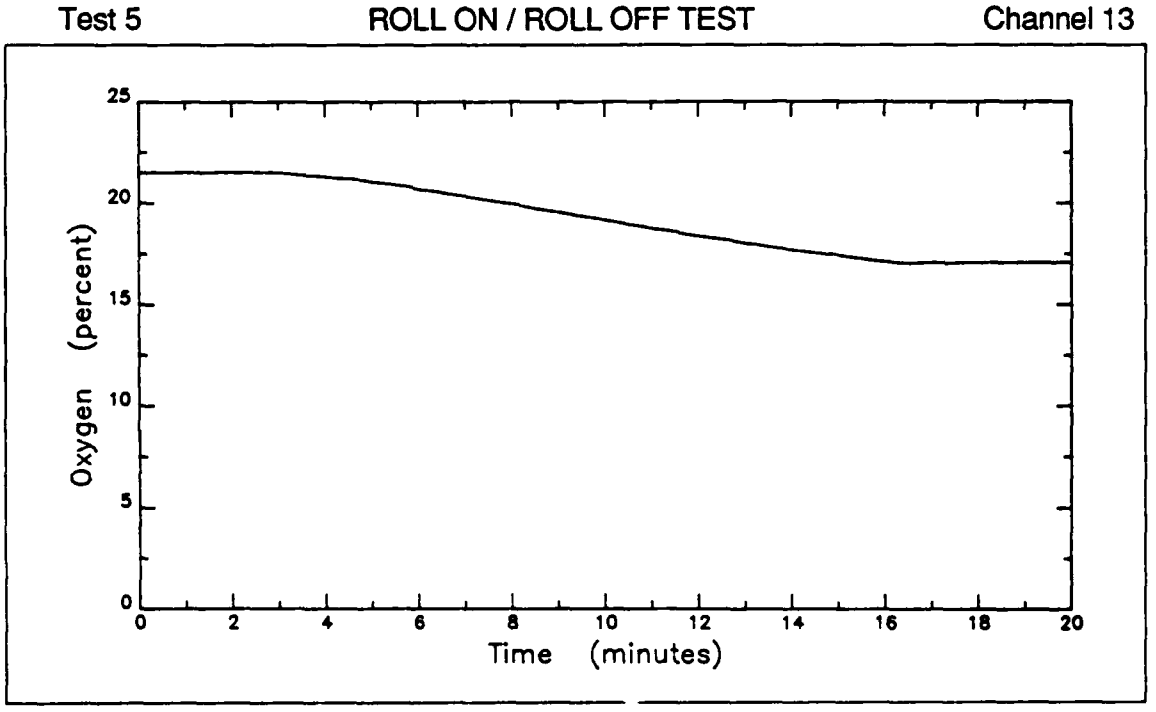



d. Test Location - Automobile 12A

**FIGURE B 5-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test Location - Automobile 9B



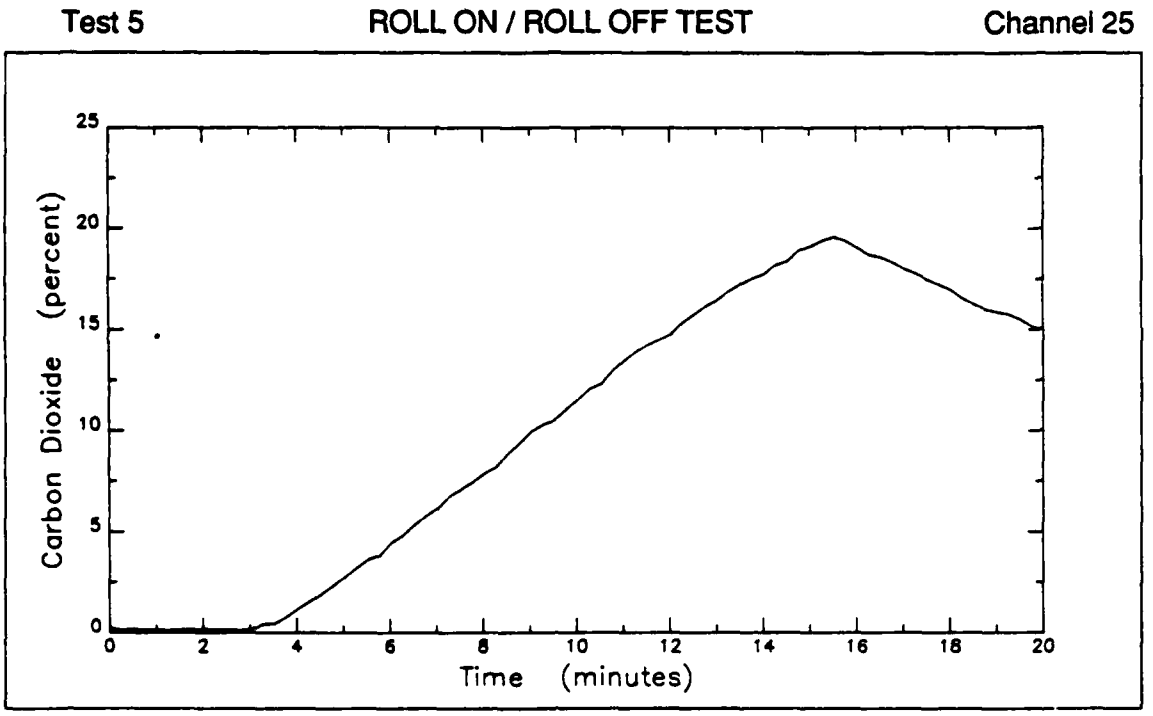

f. Test Location - Automobile 12B

**FIGURE B 5-6. PERCENT OXYGEN vs TIME (cont'd)**

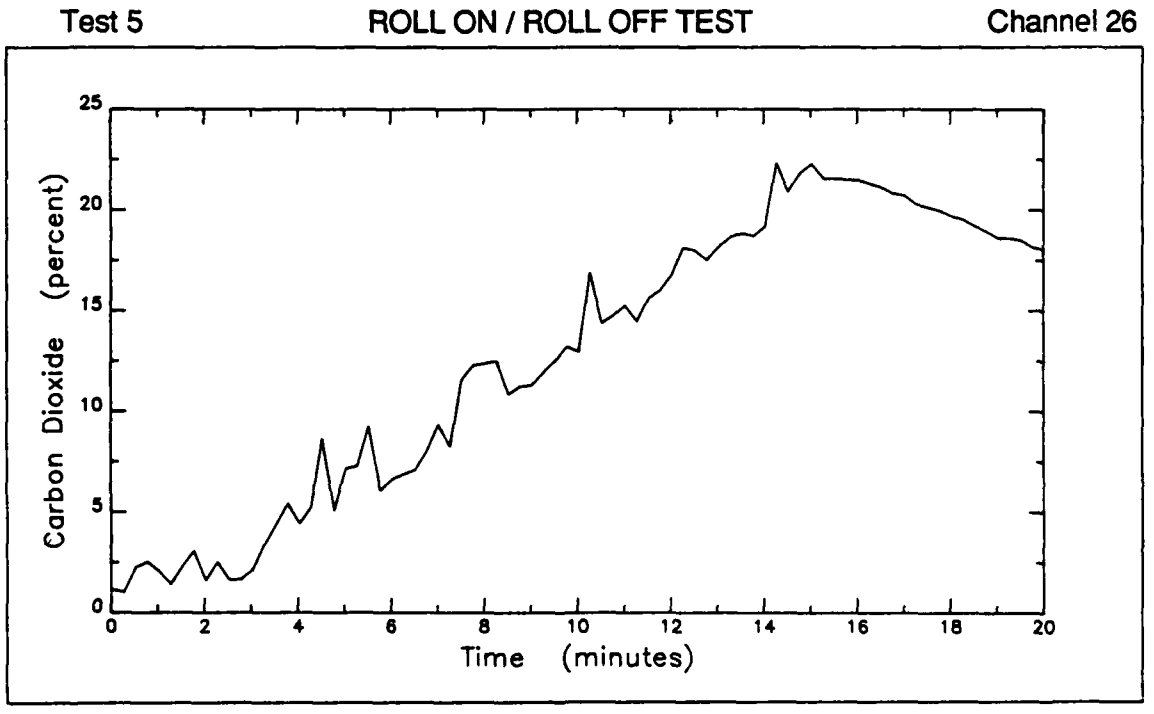
TEST 5

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 14.7 | 18.6 | 15.5 | 19.6 | |
| 26 | Auto 10A | 14.7 | 21.5 | 15.0 | 22.3 | |
| 27 | Auto 11A | 14.7 | 26.4 | 16.3 | 28.5 | |
| 28 | Auto 12A | 14.7 | 25.1 | 17.5 | 28.4 | |
| 29 | Auto 9C | 14.7 | 24.4 | 15.3 | 25.4 | |
| 30 | Auto 3A | 14.7 | 12.6 | 18.3 | 17.1 | |
| 31 | Auto 9B | 14.7 | -- | -- | -- | No reading above zero |
| 32 | Auto 12B | 14.7 | 29.6 | 20.3 | 35.3 | |
| 33 | Auto 3B | 14.7 | 22.1 | 16.0 | 23.6 | |
| | | AVERAGE | 20.0 | 16.3 | 23.6 | |

FIGURE B 5-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

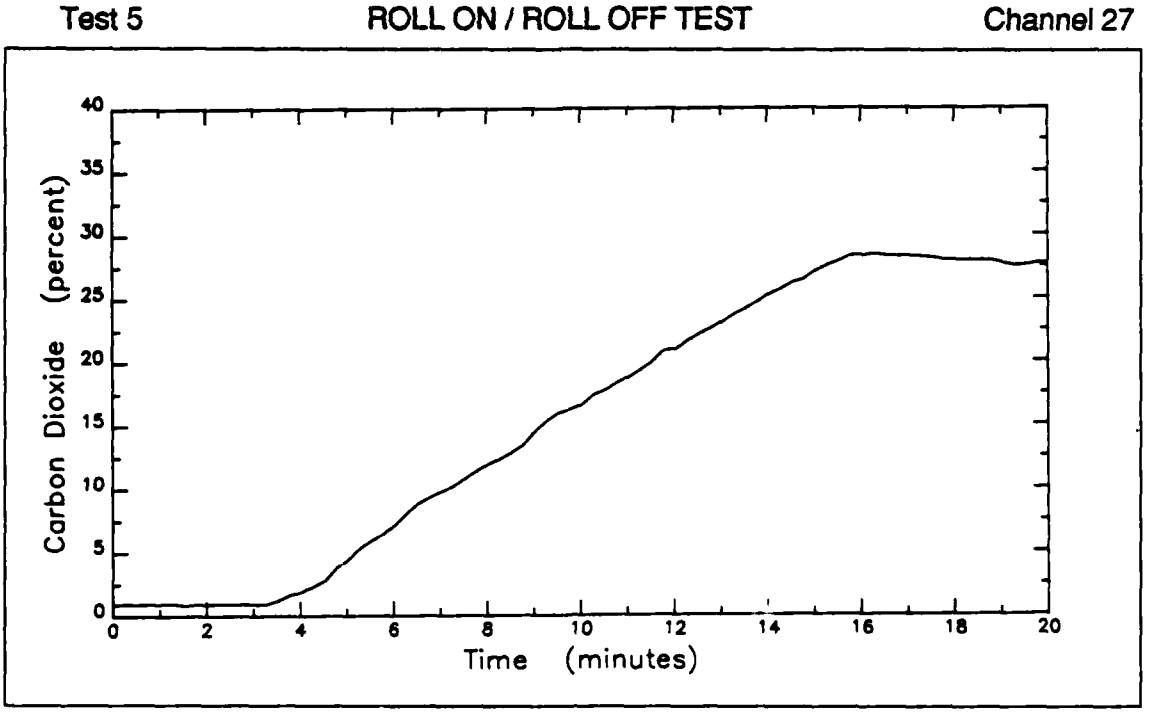



a. Test location - Automobile 9A

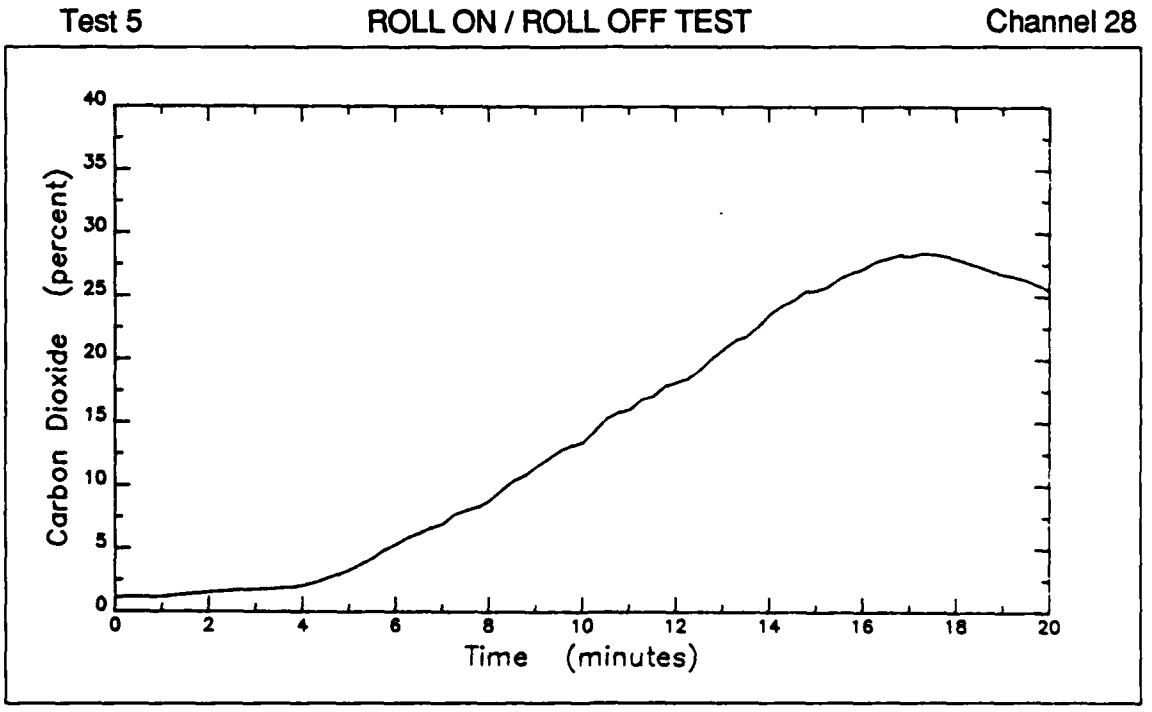



b. Test location - Automobile 10A

**FIGURE B 5-8. PERCENT CARBON DIOXIDE vs TIME**

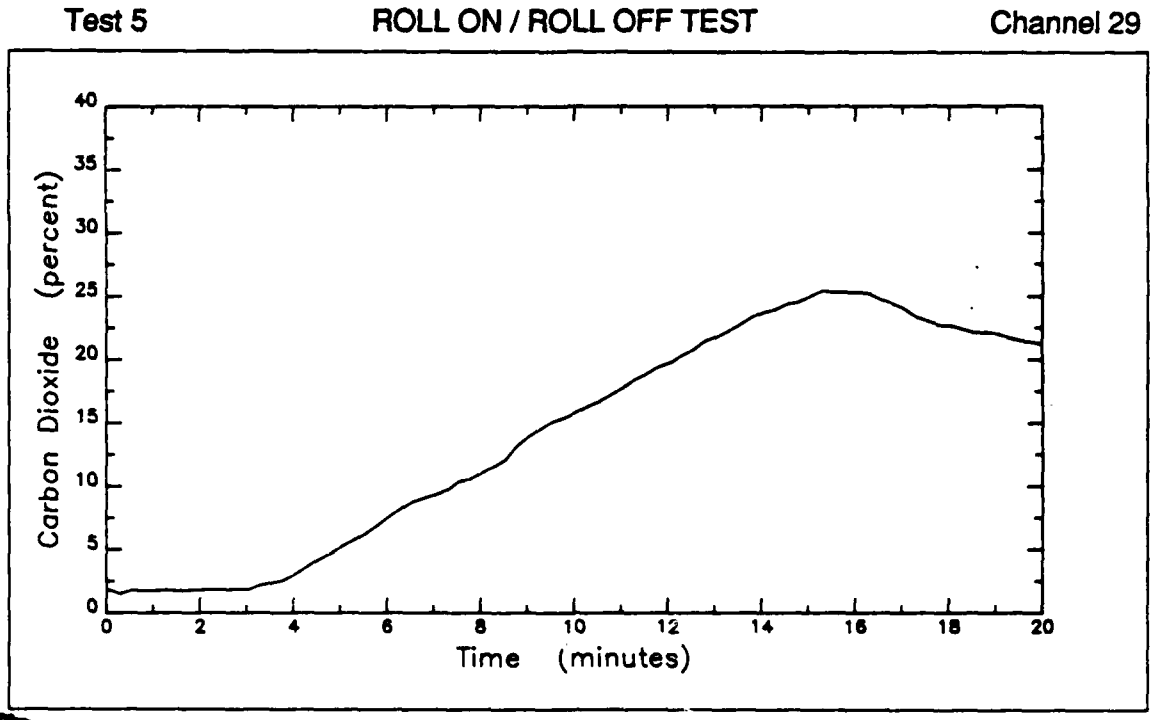



c. Test location - Automobile 11A

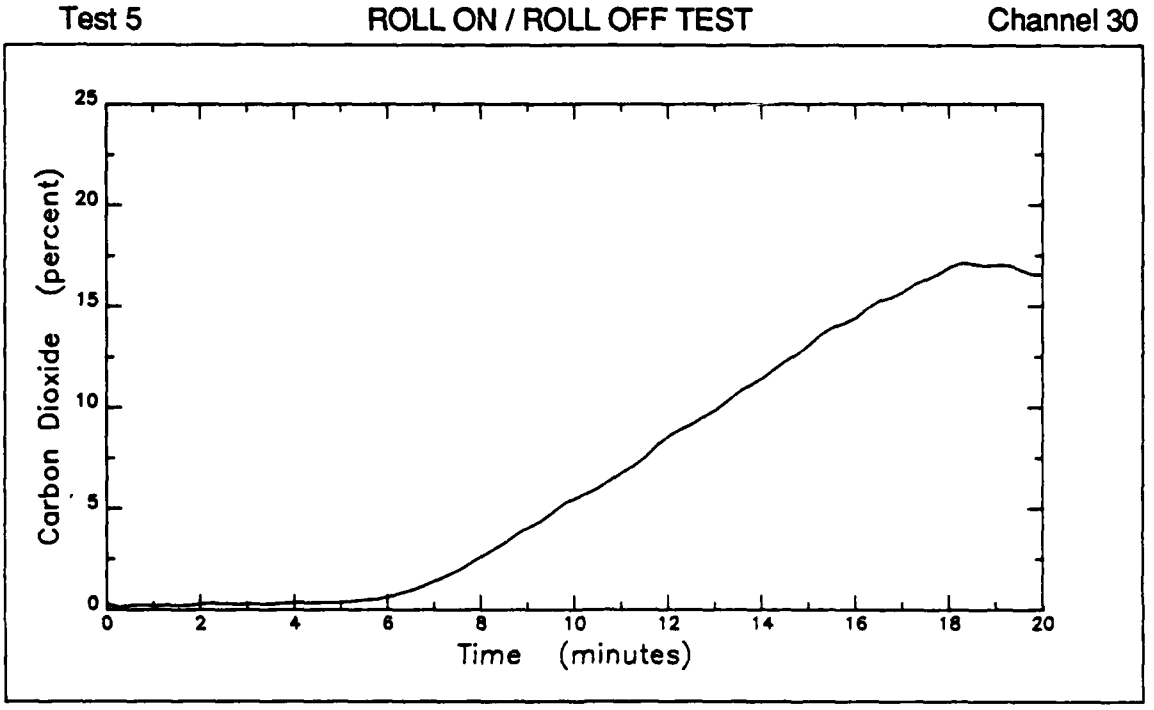



d. Test location - Automobile 12A

**FIGURE B 5-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

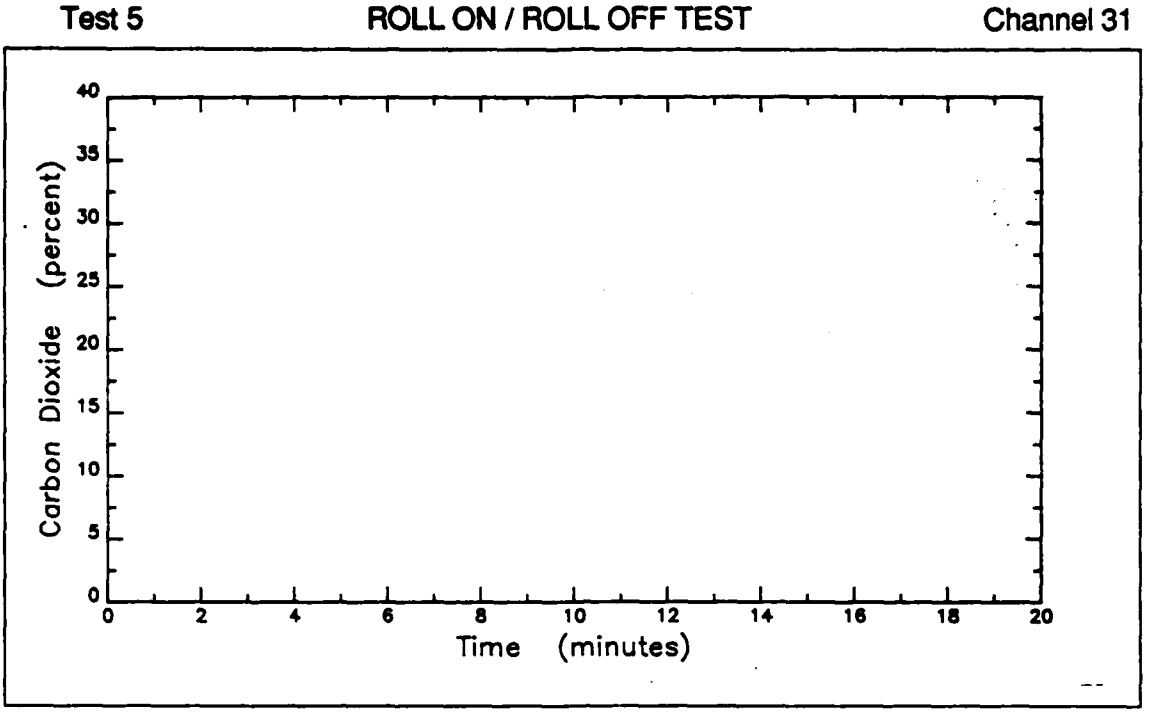



e. Test location - Automobile 9C

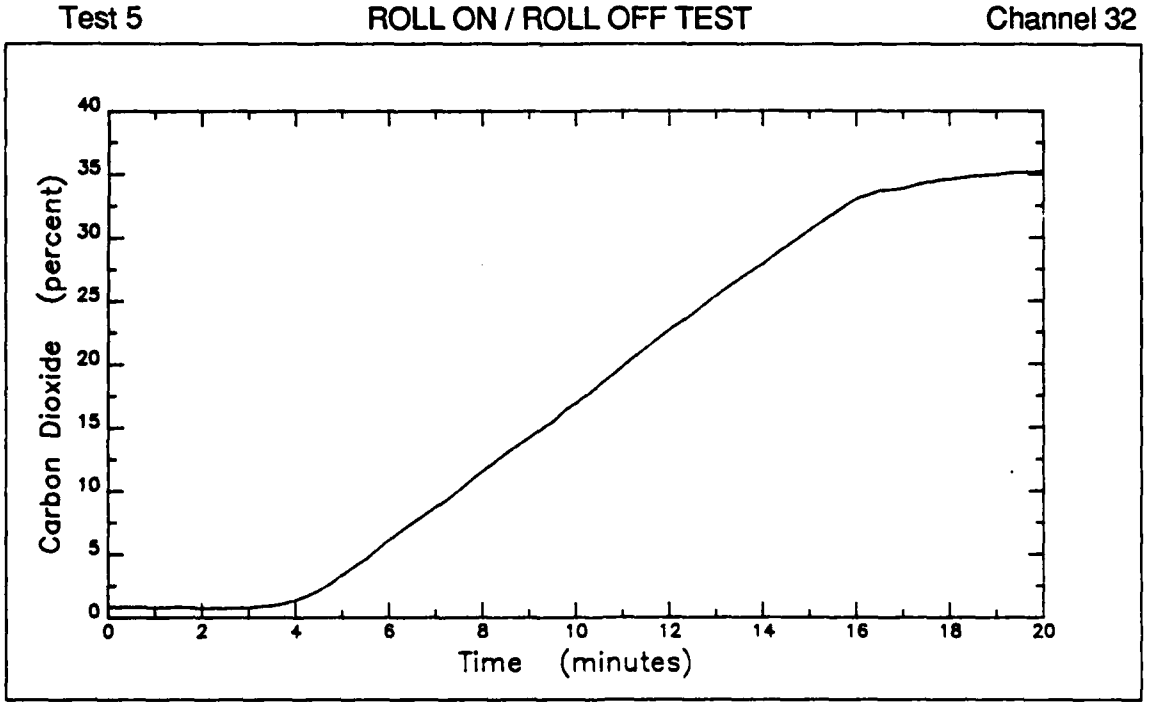



f. Test location - Automobile 3A

**FIGURE B 5-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

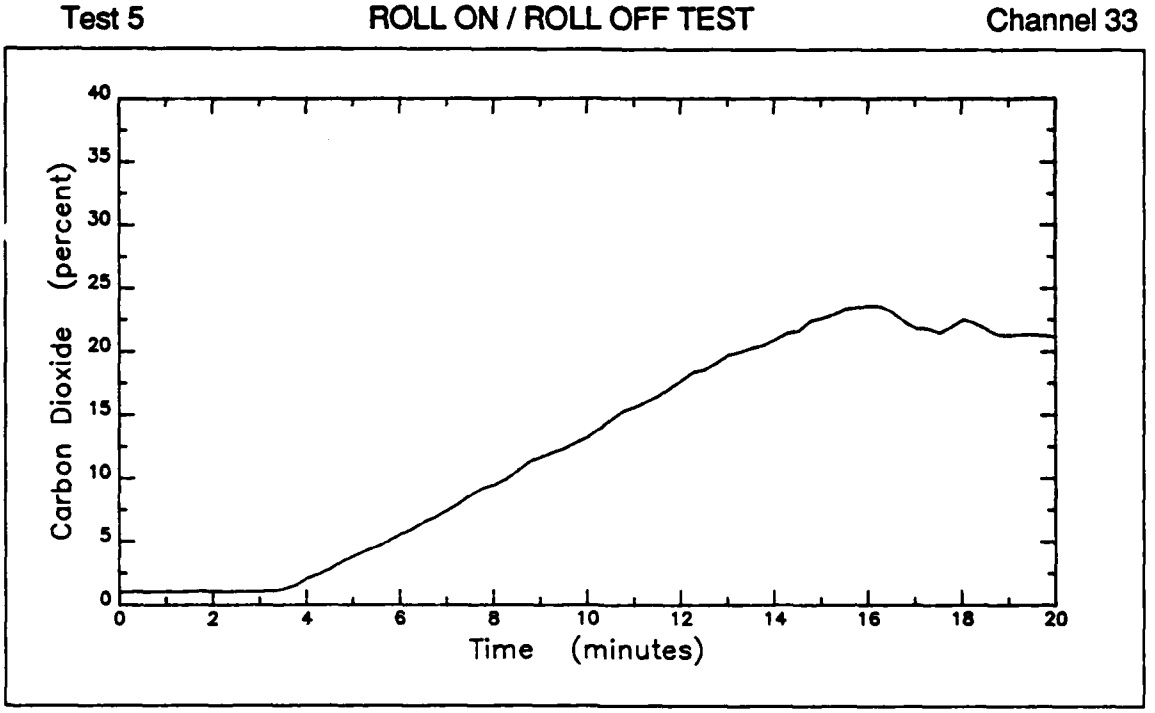



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 5-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 5-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

# TEST 6

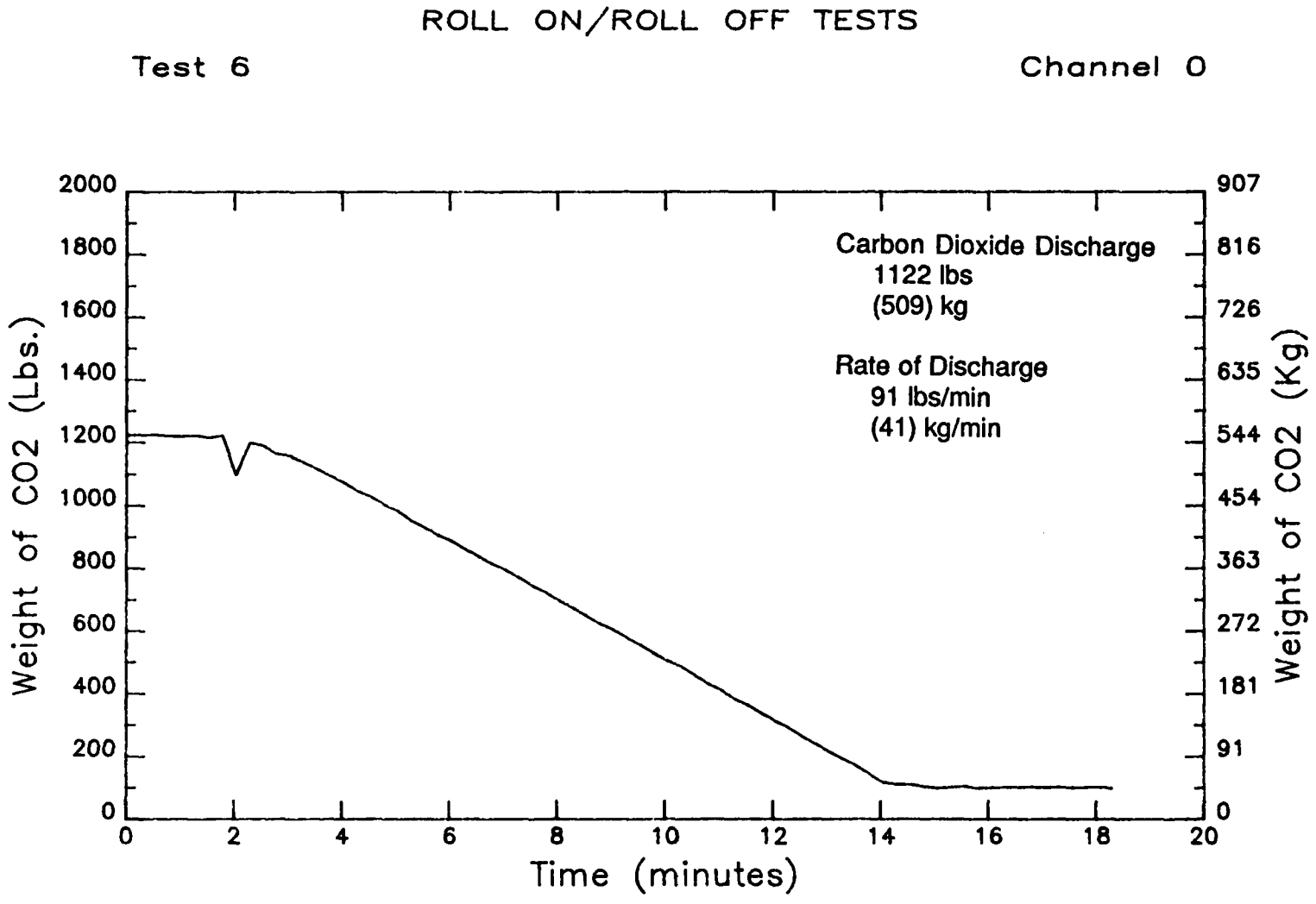



FIGURE B 6-1. Weight of Carbon Dioxide vs Time

ROLL ON/ROLL OFF TESTS

Test6

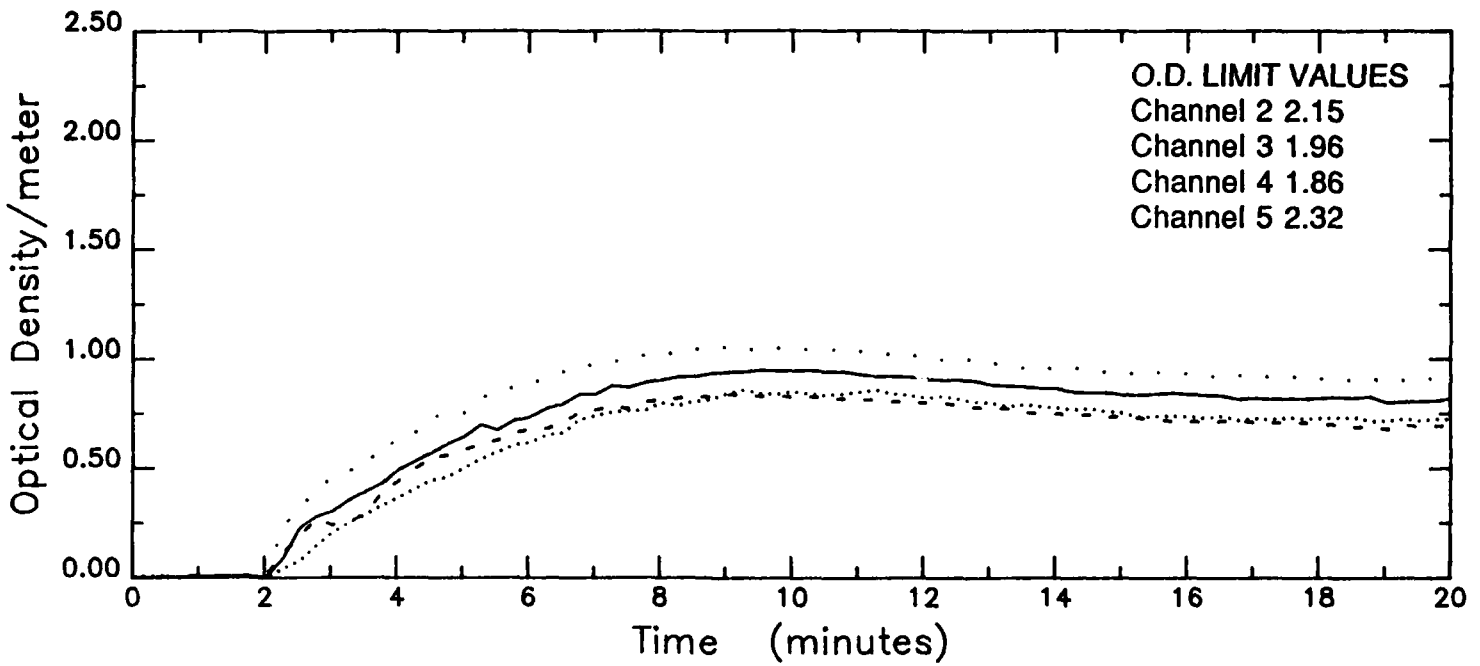



FIGURE B 6-2. Optical Density vs Time
Data Channels 2, 3, 4, 5

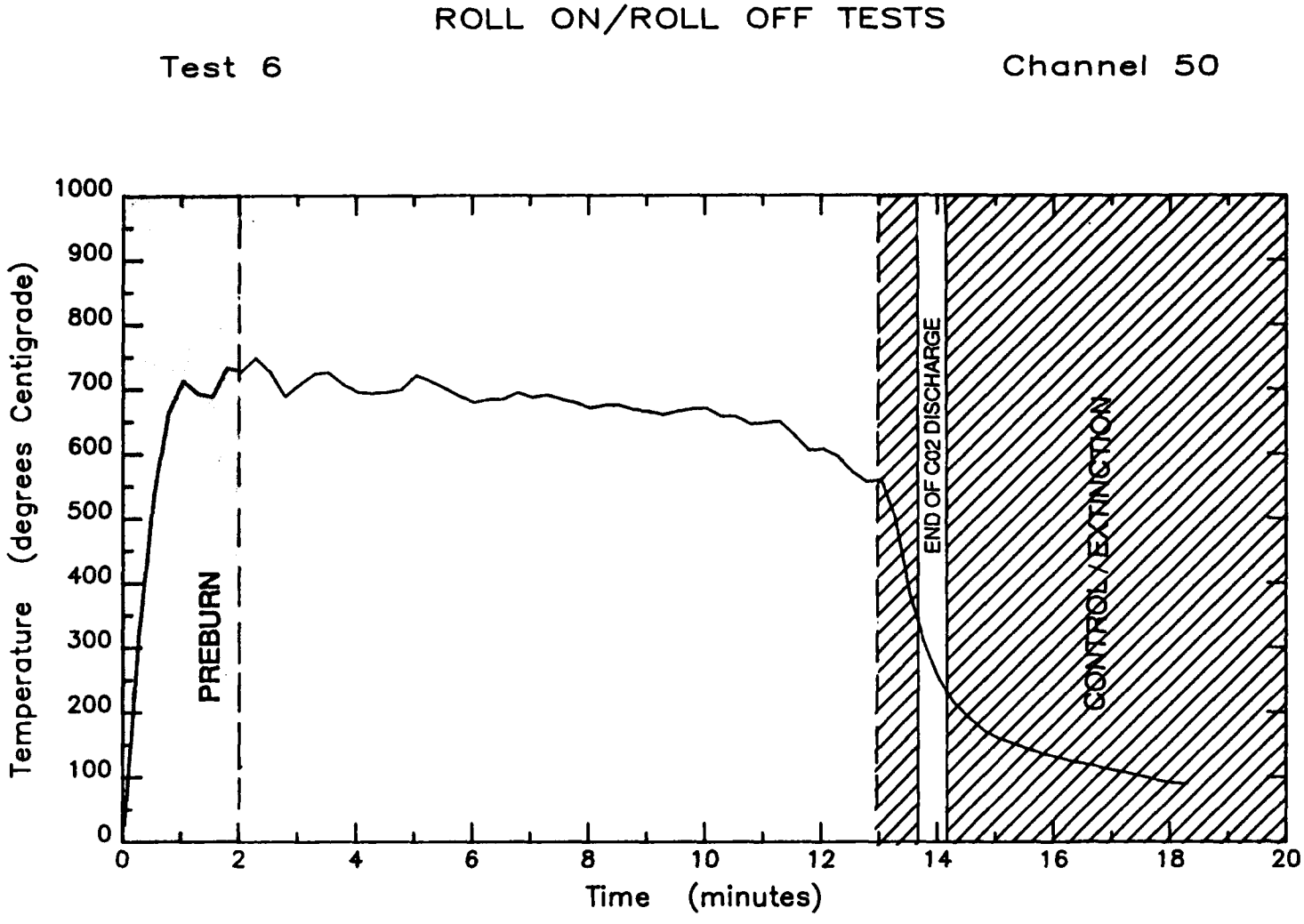
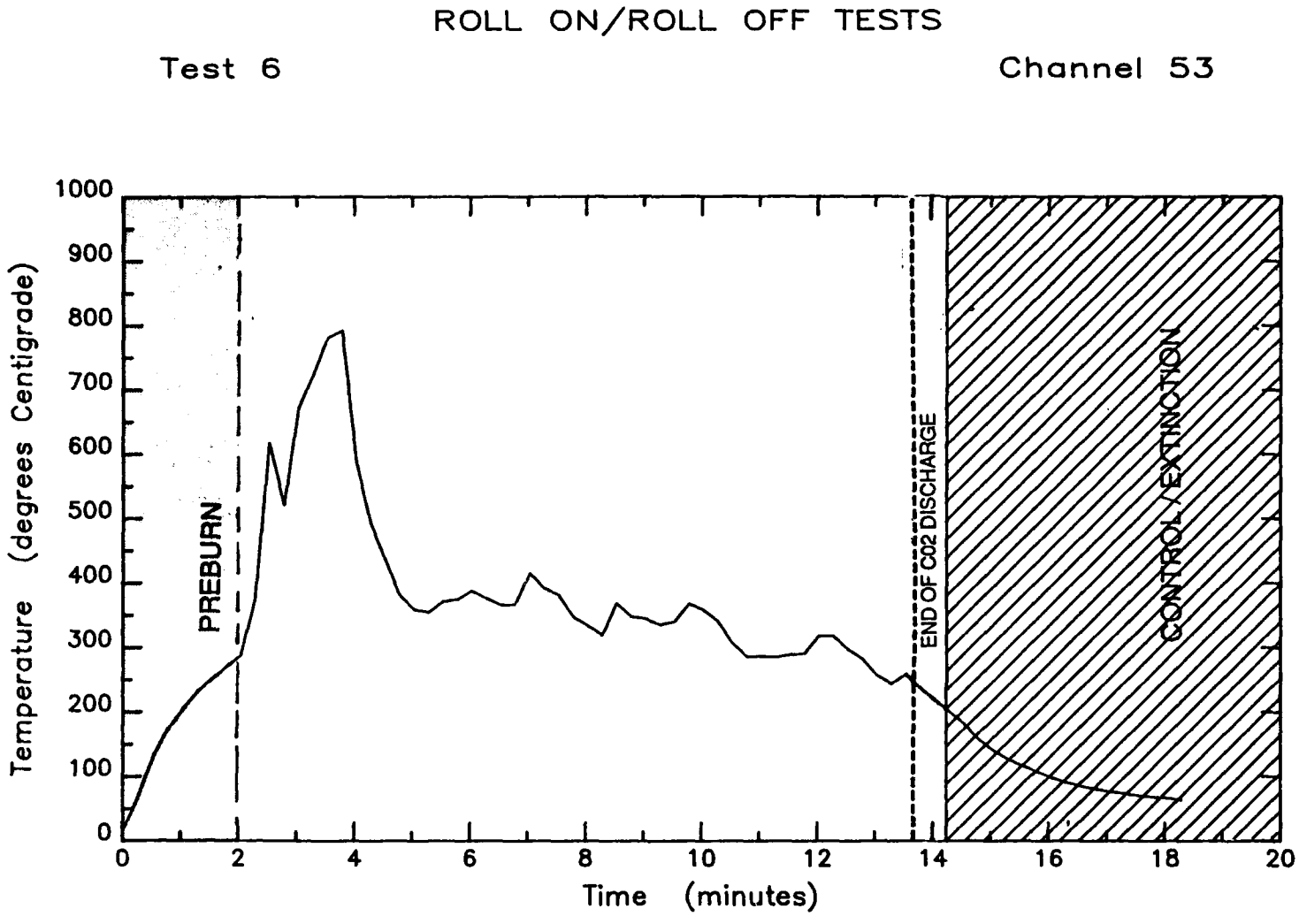



FIGURE B 6-3. Temperature vs Time - Location 9A




B 6-4

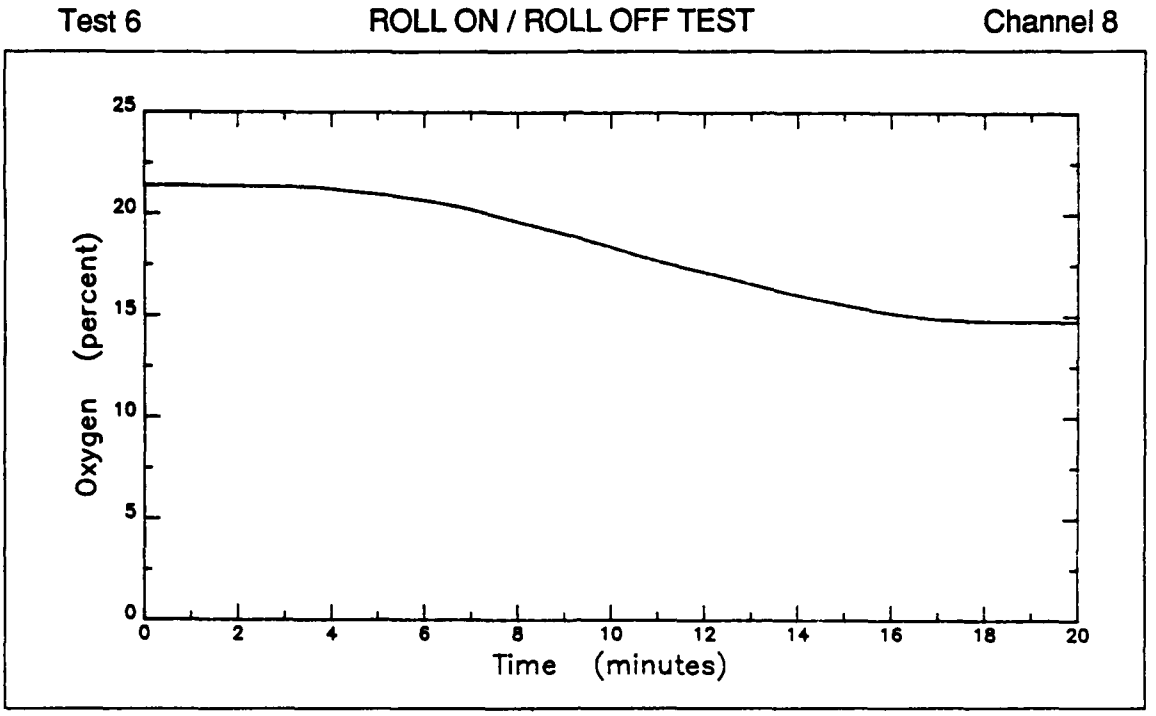
FIGURE B 6-4. Temperature vs Time - Location 10A

TEST 6

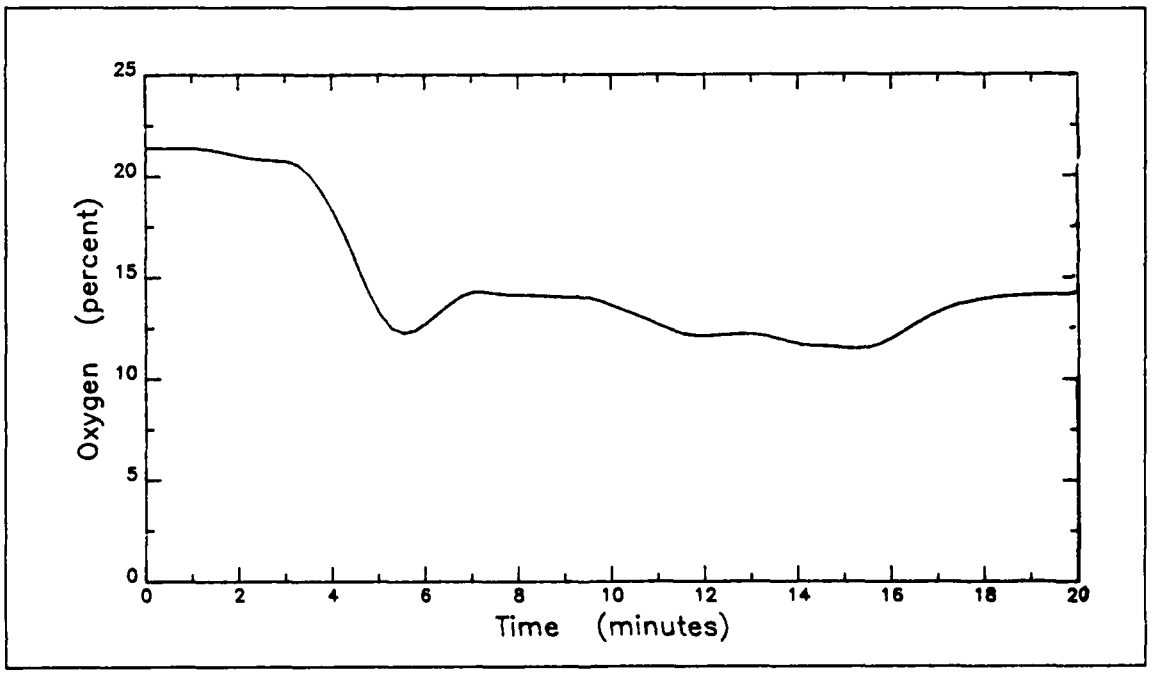
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 13.5 | 16.3 | 2.0 | 14.7 | |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 13.5 | 15.7 | 18.3 | 14.4 | 14.4% OXYGEN @ 17.0 MINUTES |
| 11 | Auto 11A | 13.5 | 16.6 | 15.8 | 15.9 | |
| 12 | Auto 9B | 13.5 | 16.5 | 15.8 | 15.9 | |
| 13 | Auto 12B | 13.5 | 17.8 | 16.3 | 17.2 | |
| | | AVERAGE | 16.6 | 16.6 | 15.6 | |



FIGURE B 6-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

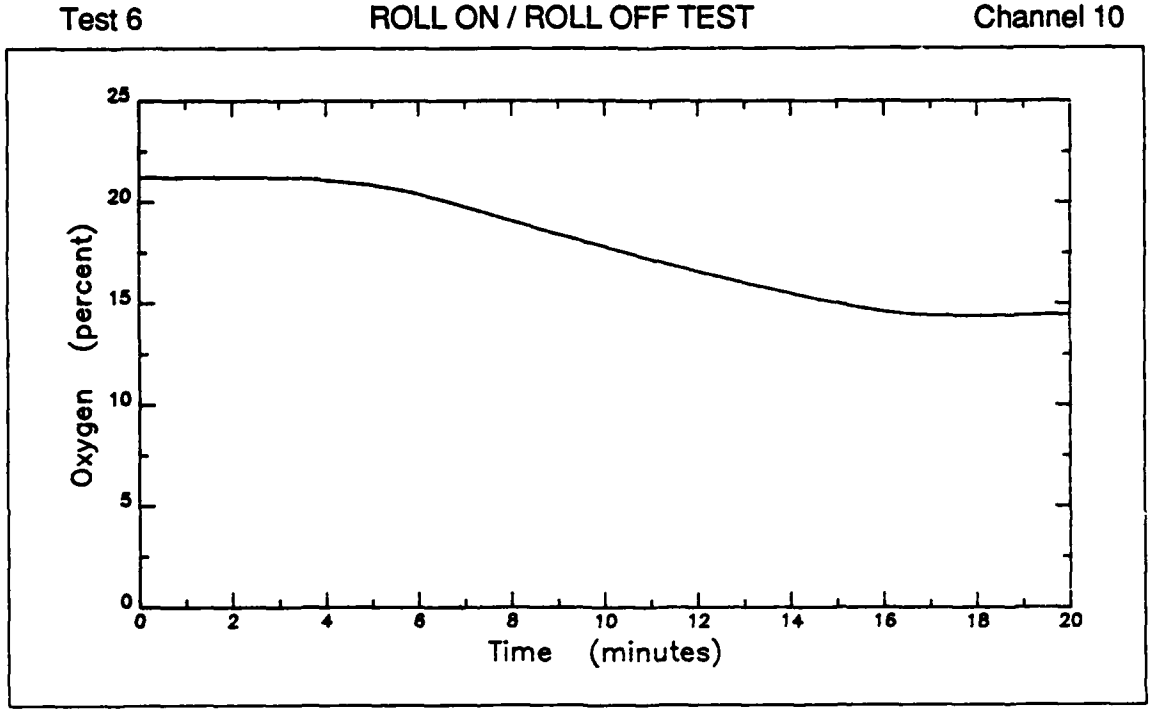



a. Test Location - Automobile 9A

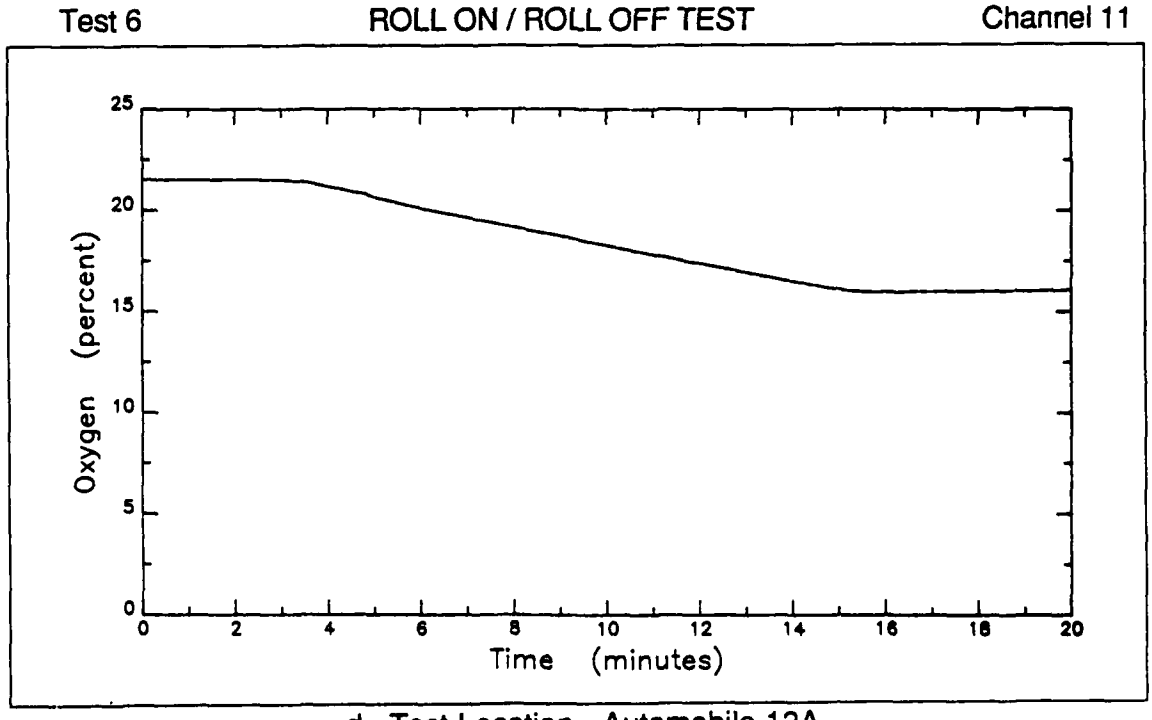



b. Test Location - Automobile 10A

**FIGURE B 6-6. PERCENT OXYGEN vs TIME**

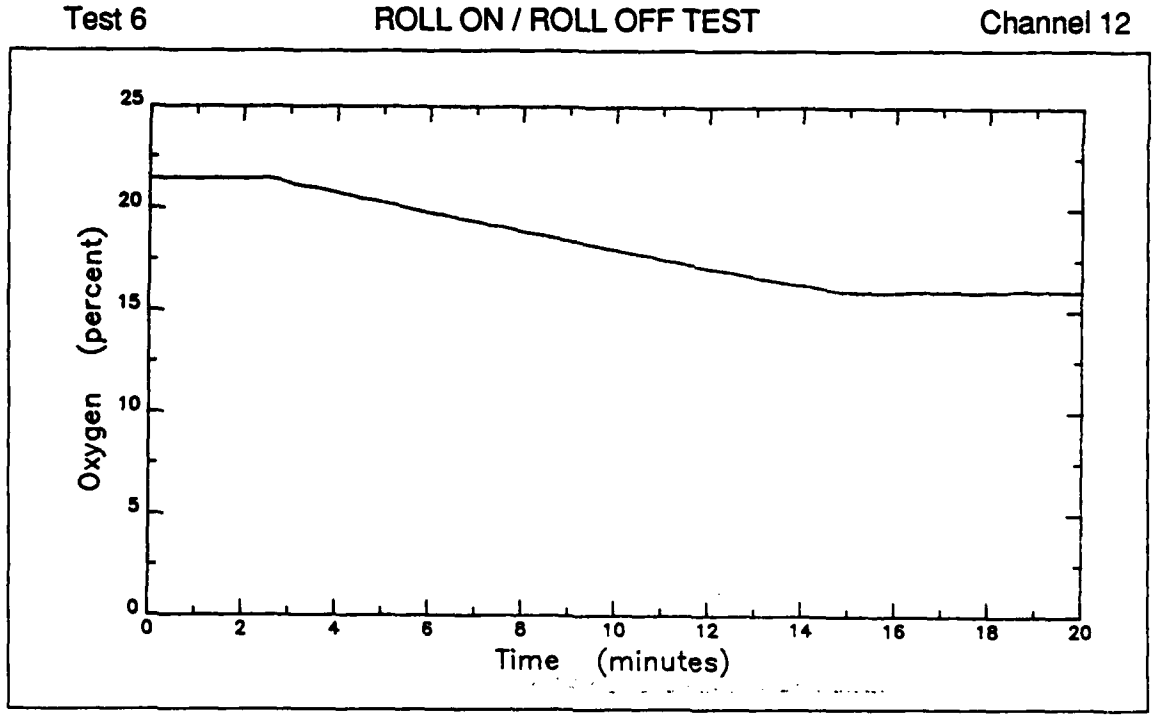



c. Test Location - Automobile 11A

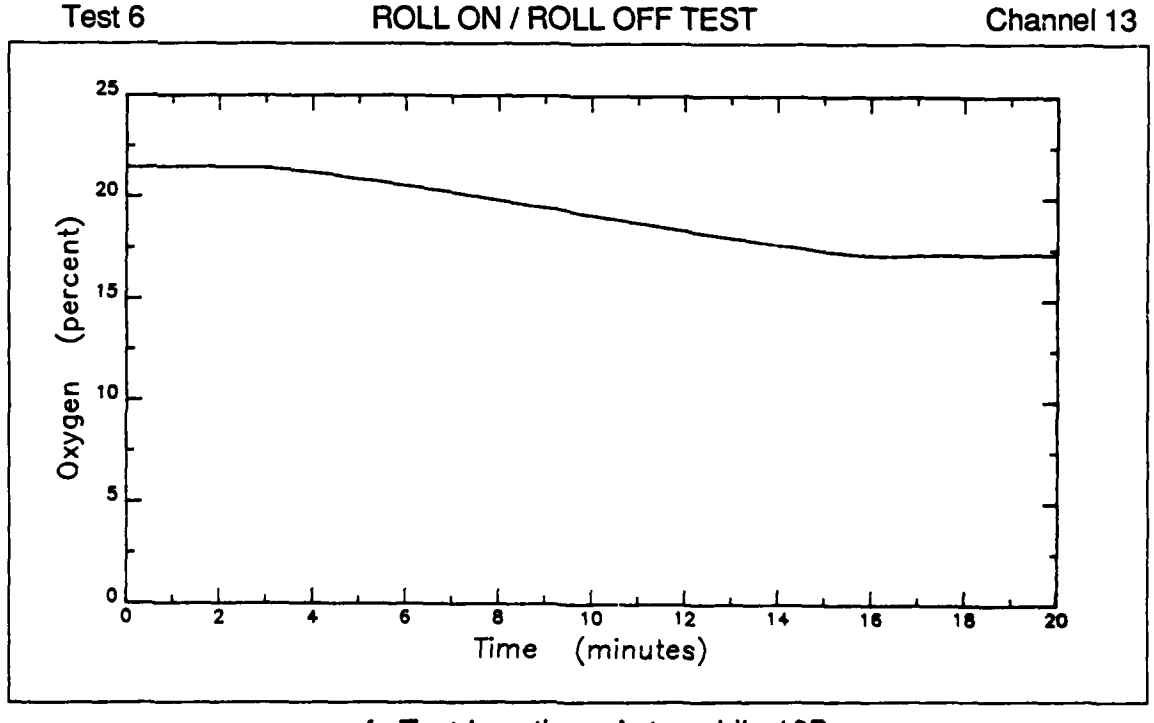



d. Test Location - Automobile 12A

**FIGURE B 6-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test Location - Automobile 9B



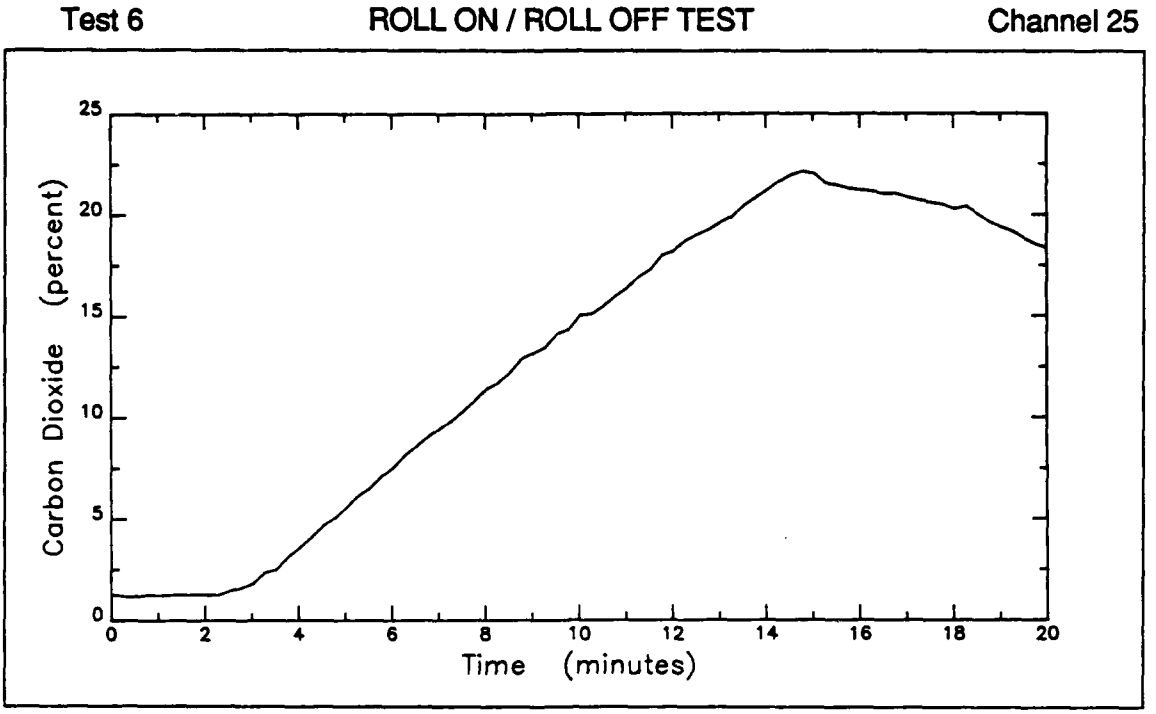

f. Test Location - Automobile 12B

**FIGURE B 6-6. PERCENT OXYGEN vs TIME (cont'd)**

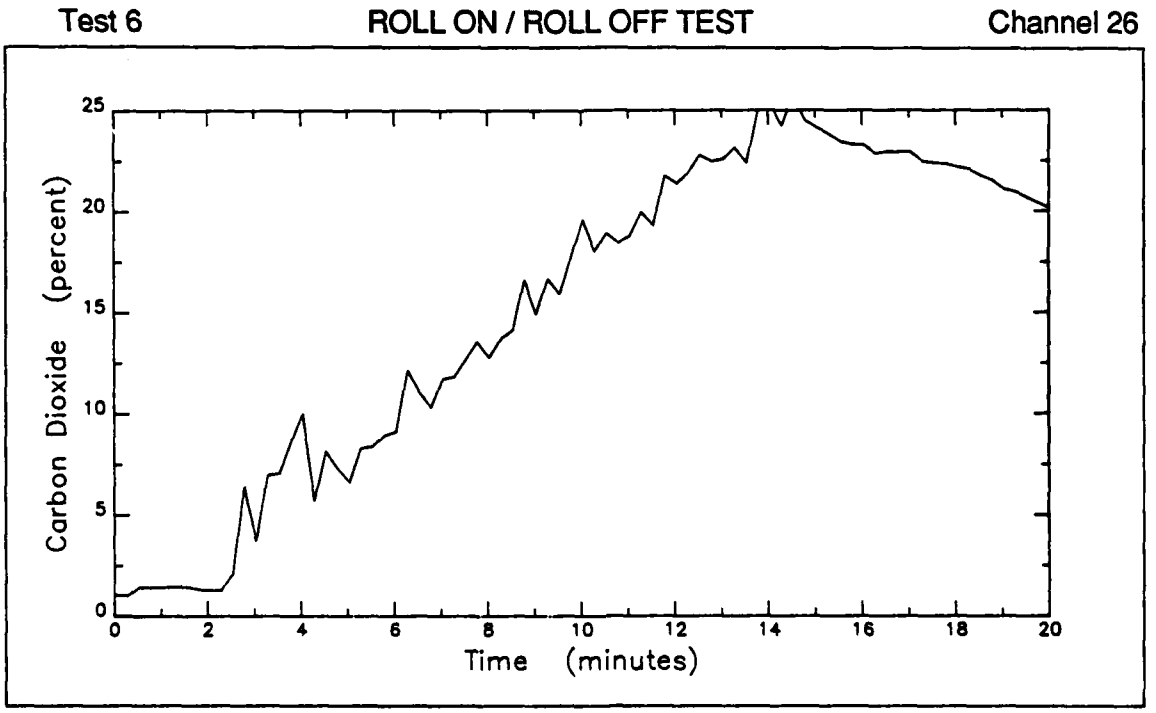
TEST 6

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 13.5 | 20.2 | 14.8 | 22.1 | |
| 26 | Auto 10A | 13.5 | 22.7 | 14.5 | 25.7 | |
| 27 | Auto 11A | 13.5 | 25.6 | 15.3 | 28.7 | |
| 28 | Auto 12A | 13.5 | 26.3 | 16.3 | 30.3 | |
| 29 | Auto 9C | 13.5 | 24.7 | 15.3 | 26.8 | |
| 30 | Auto 3A | 13.5 | 20.7 | 15.8 | 22.4 | |
| 31 | Auto 9B | 13.5 | 25.3 | 15.3 | 28.6 | |
| 32 | Auto 12B | 13.5 | 28.1 | 19.5 | 35.6 | |
| 33 | Auto 3B | 13.5 | 23.9 | 14.8 | 26.7 | |
| | | AVERAGE | 24.2 | 15.6 | 27.4 | |

FIGURE B 6-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

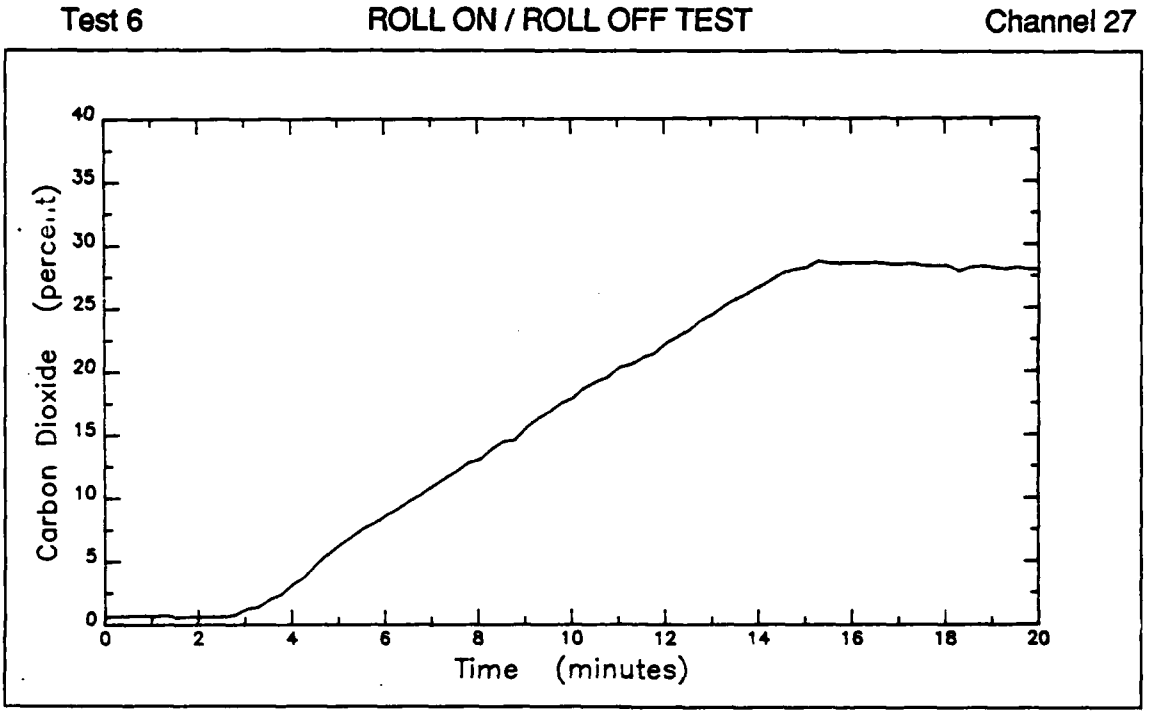



a. Test location - Automobile 9A

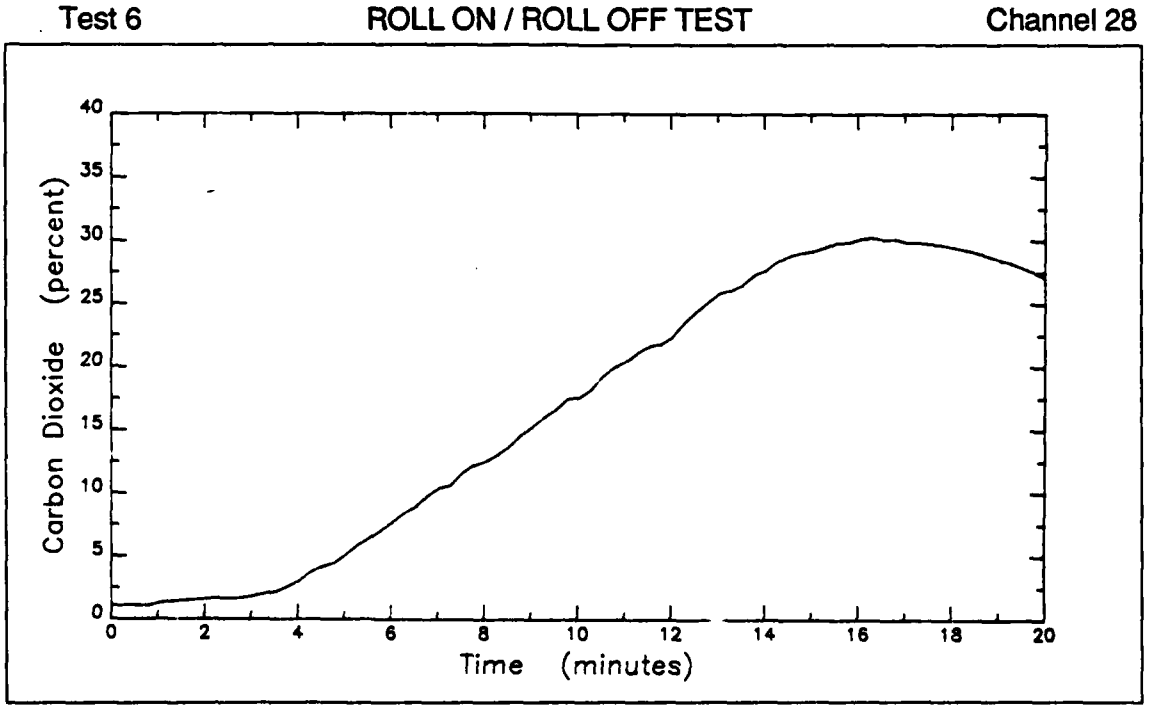



b. Test location - Automobile 10A

**FIGURE B 6-8. PERCENT CARBON DIOXIDE vs TIME**

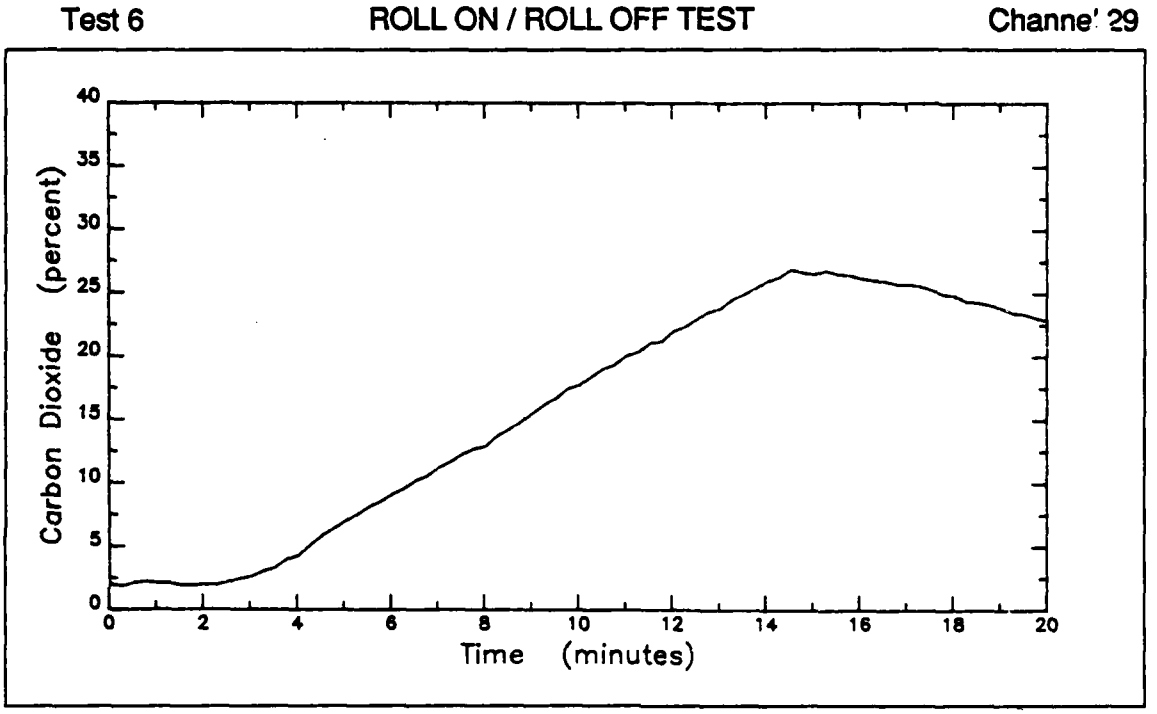



c. Test location - Automobile 11A

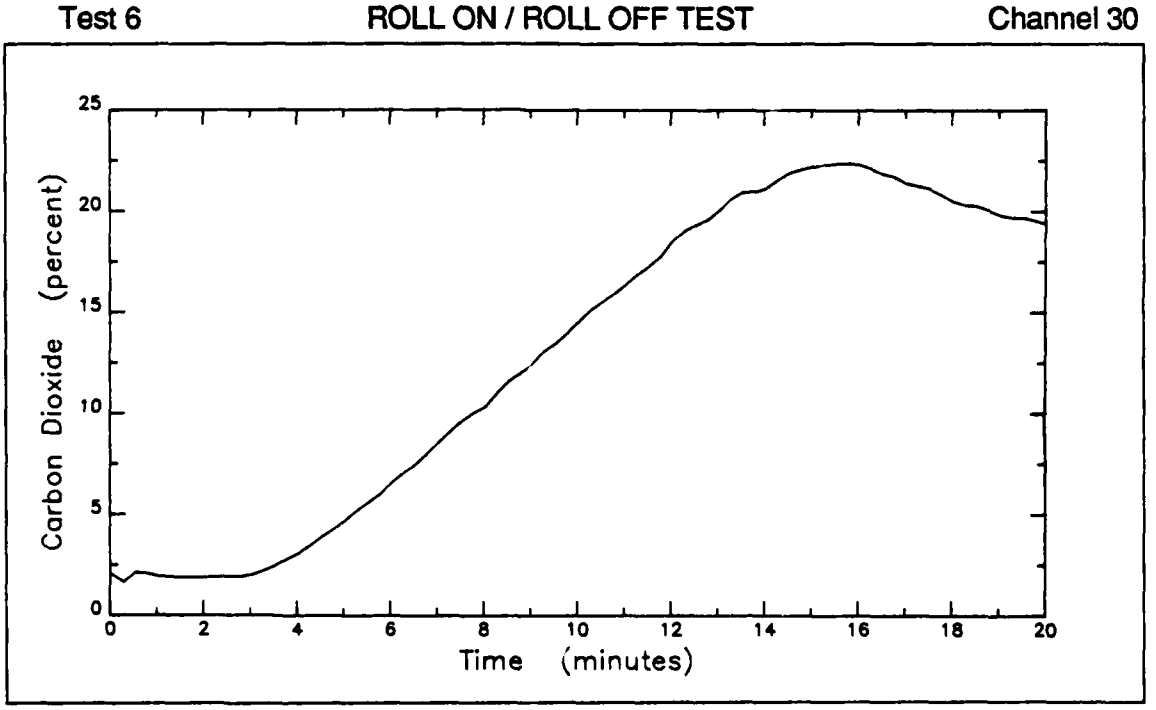



d. Test location - Automobile 12A

**FIGURE B 6-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

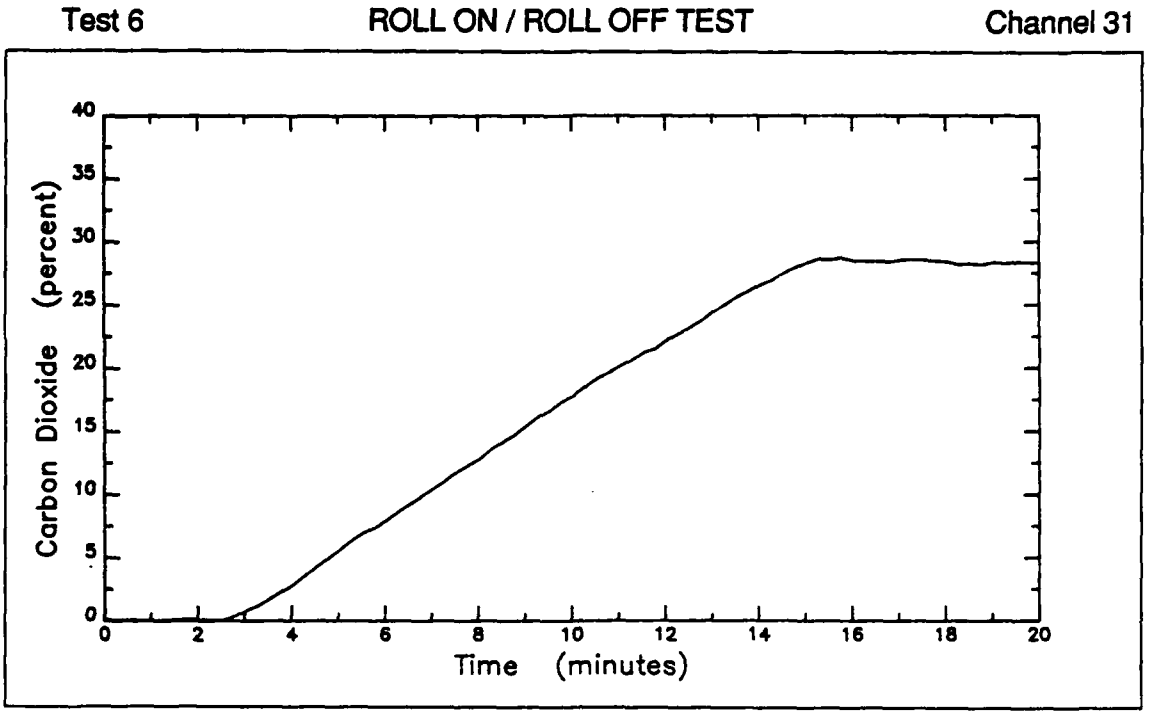



e. Test location - Automobile 9C

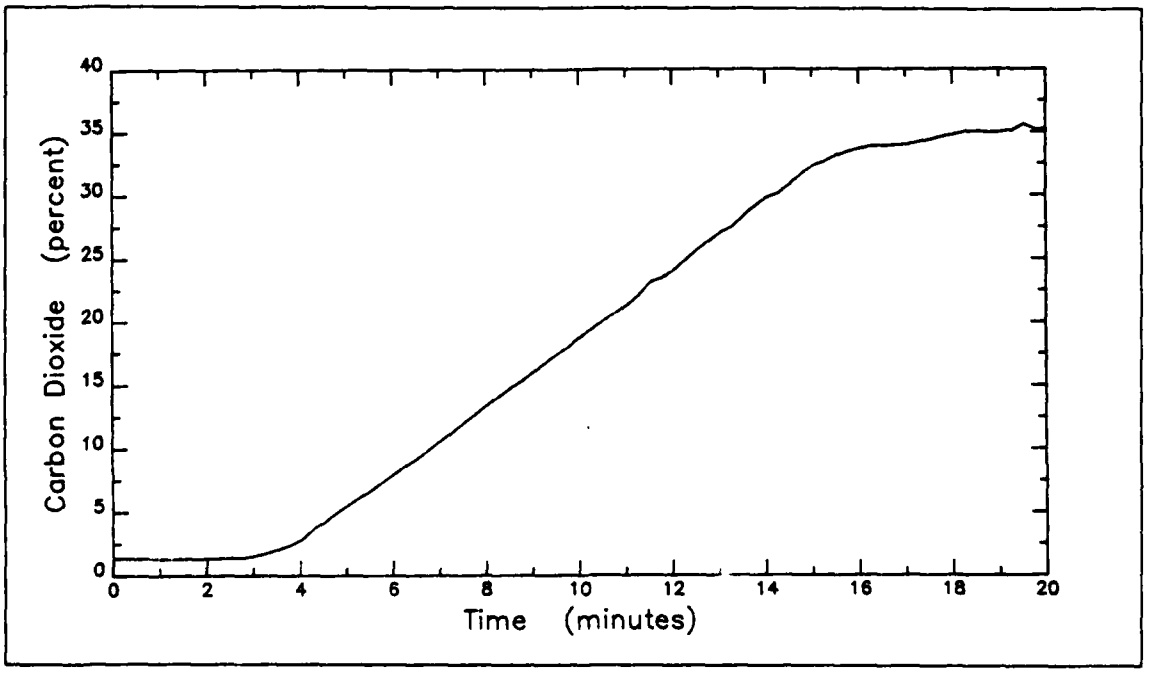



f. Test location - Automobile 3A

**FIGURE B 6-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

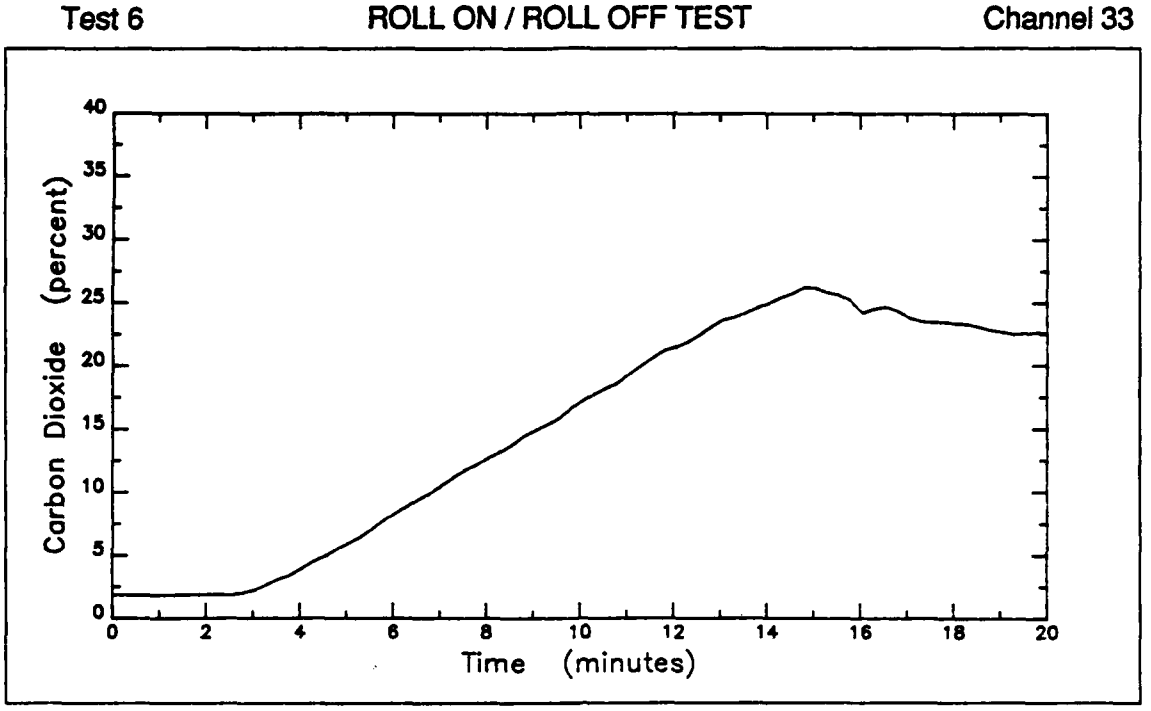



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 6-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 6-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

# TEST 7

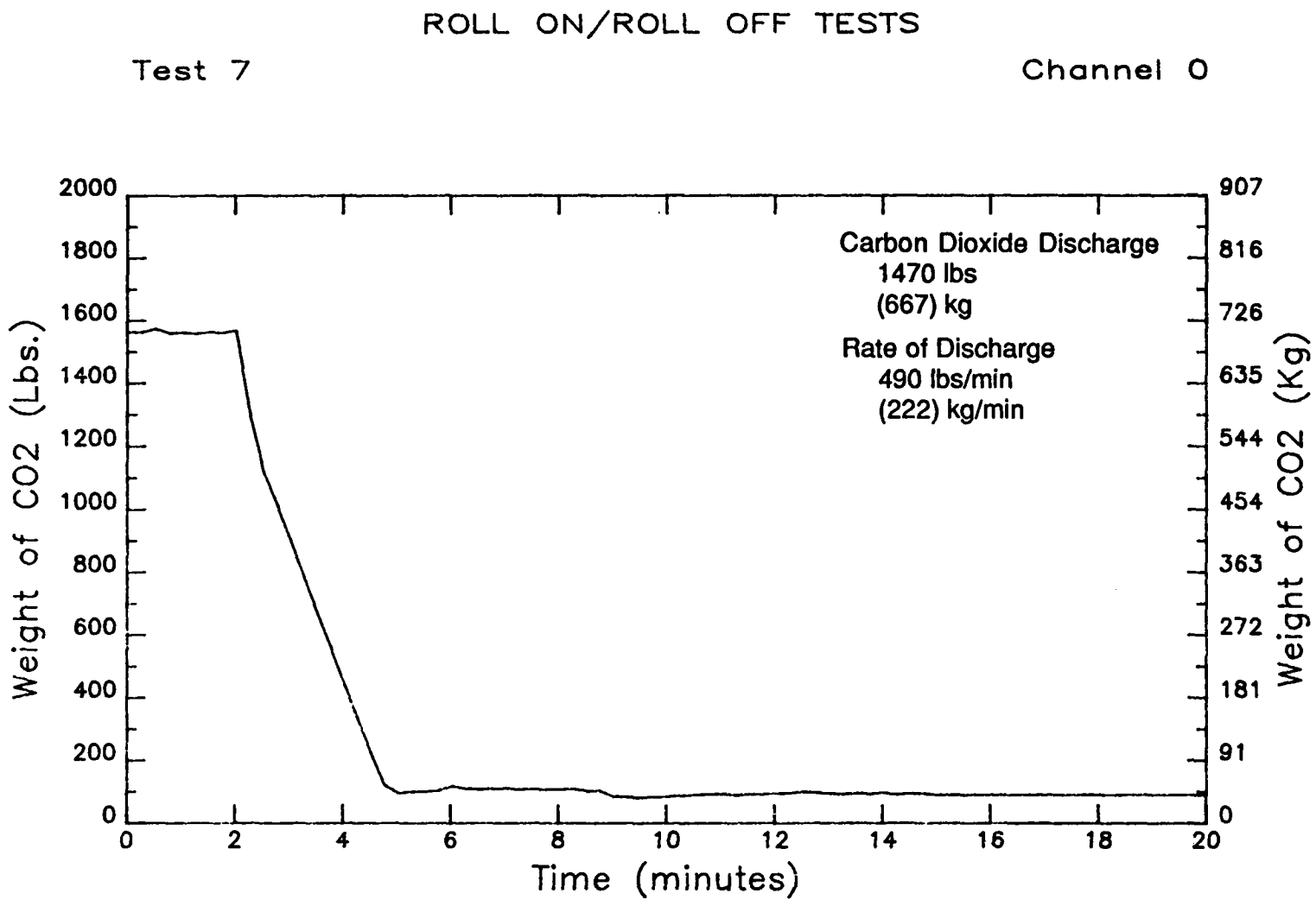
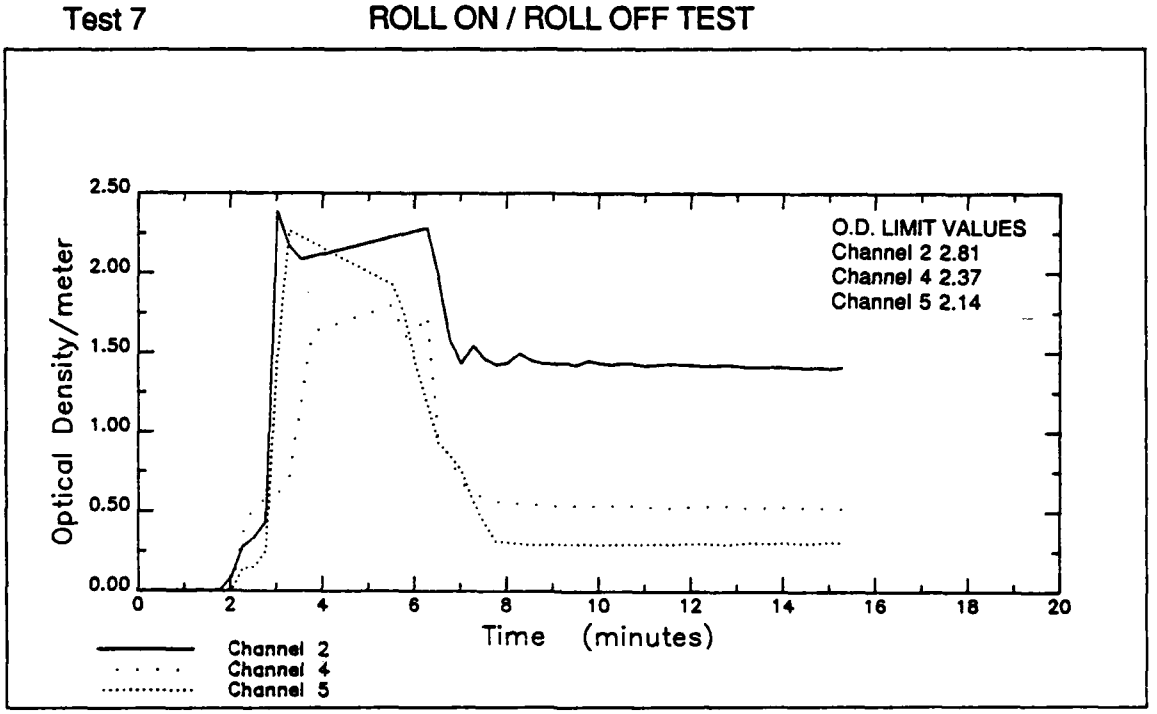
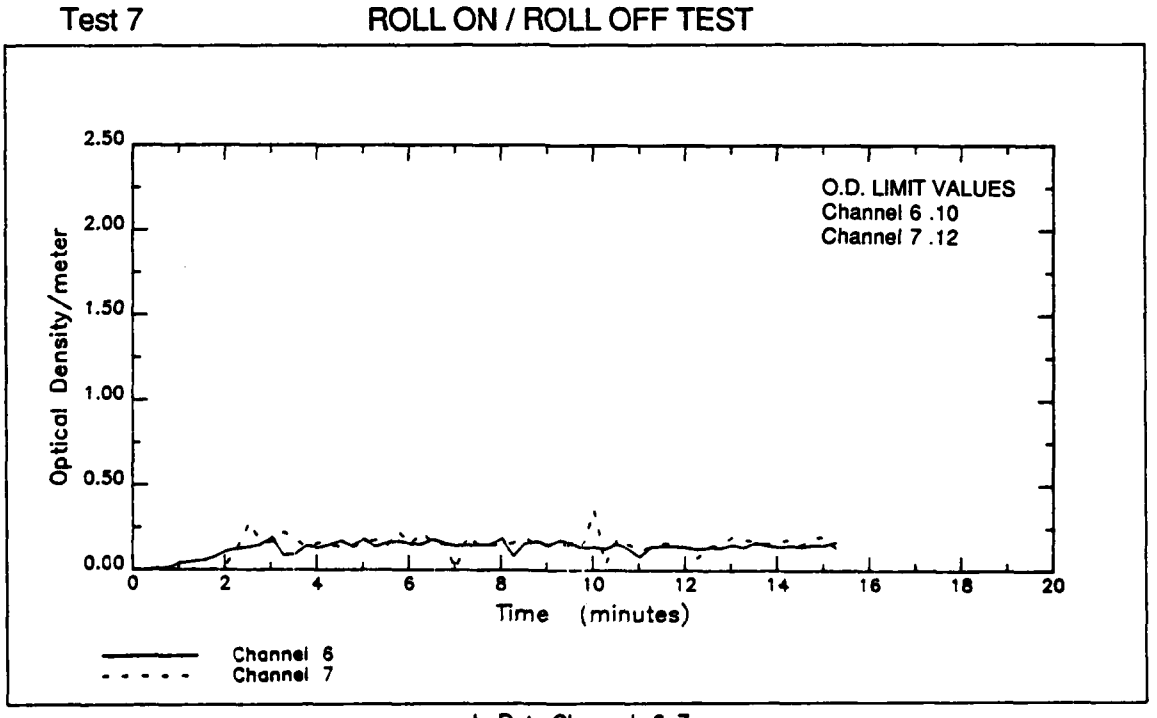



FIGURE B 7-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 7-2. OPTICAL DENSITY vs TIME**

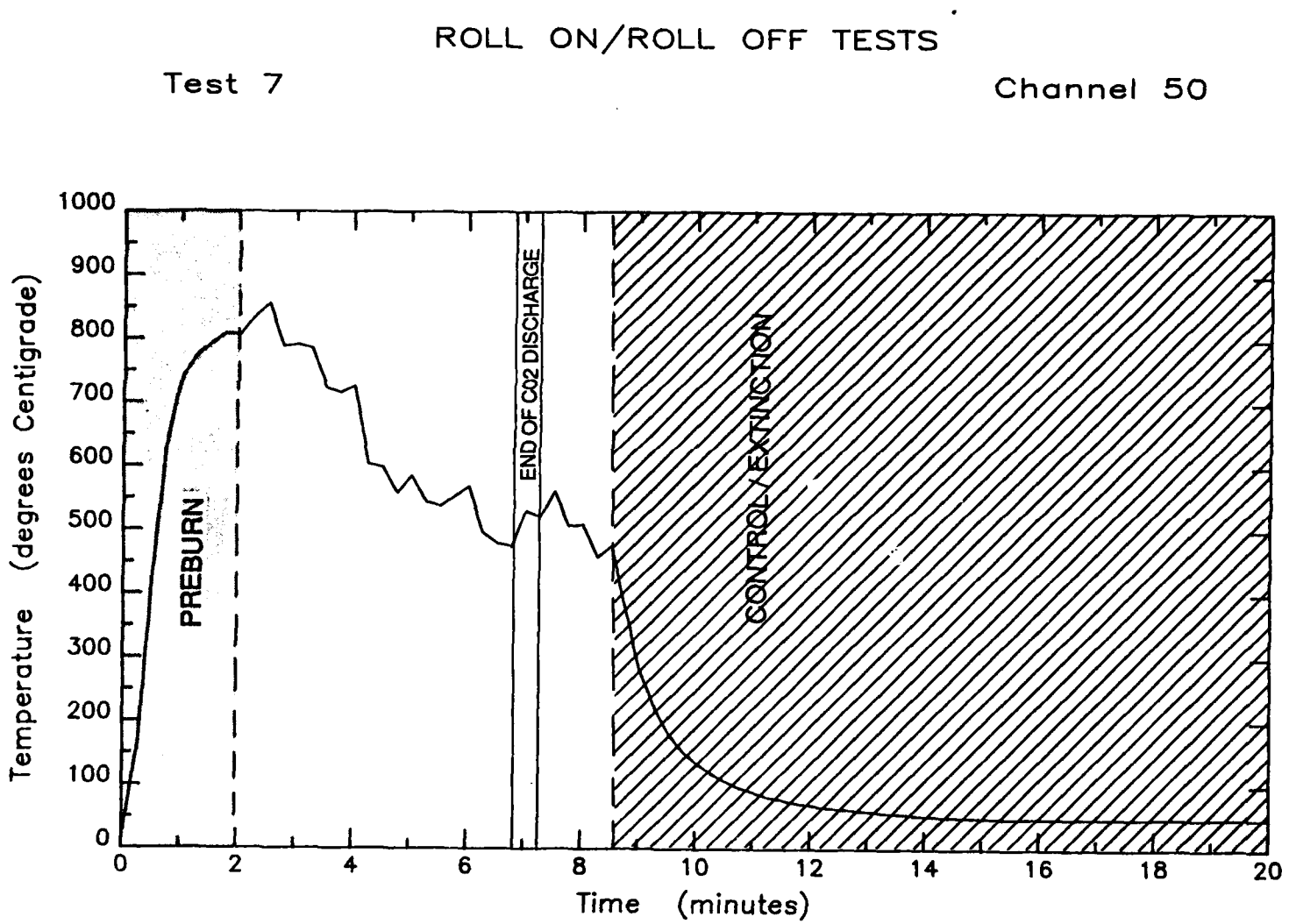
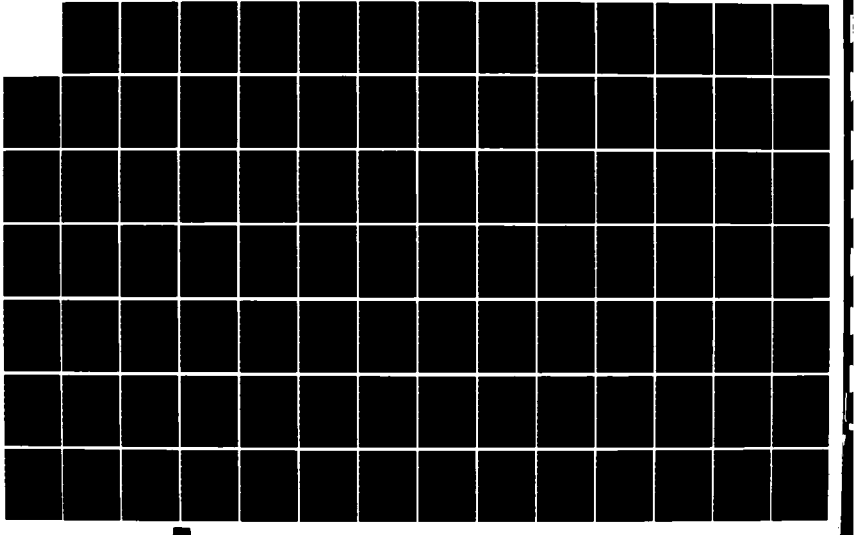
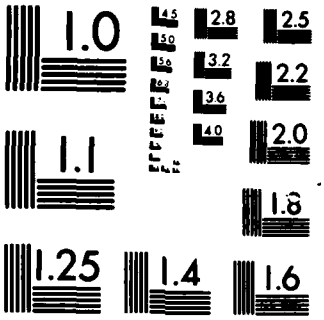



FIGURE B 7-3. Temperature vs Time - Location 9A

AD-A163 185 ROLL-ON/ROLL-OFF AUTOMOBILE TRANSPORT SHIPS - AN ASSESSMENT OF CARBON DIO.. (U) COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CT W H MCLAIN OCT 85 2/3

UNCLASSIFIED CGR/DC-13/85 USCG-D-34-85 F/G 13/12 NL






MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

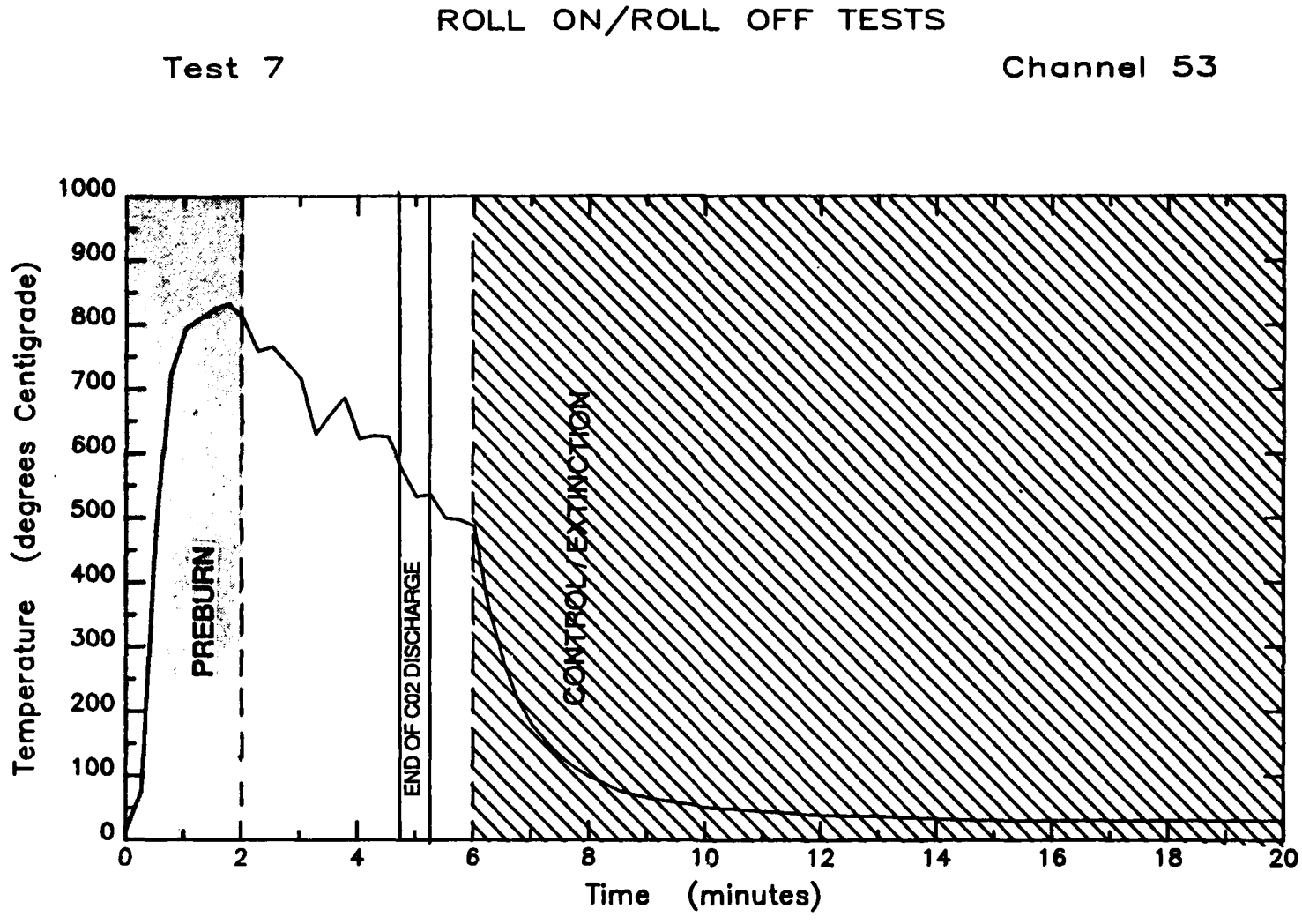


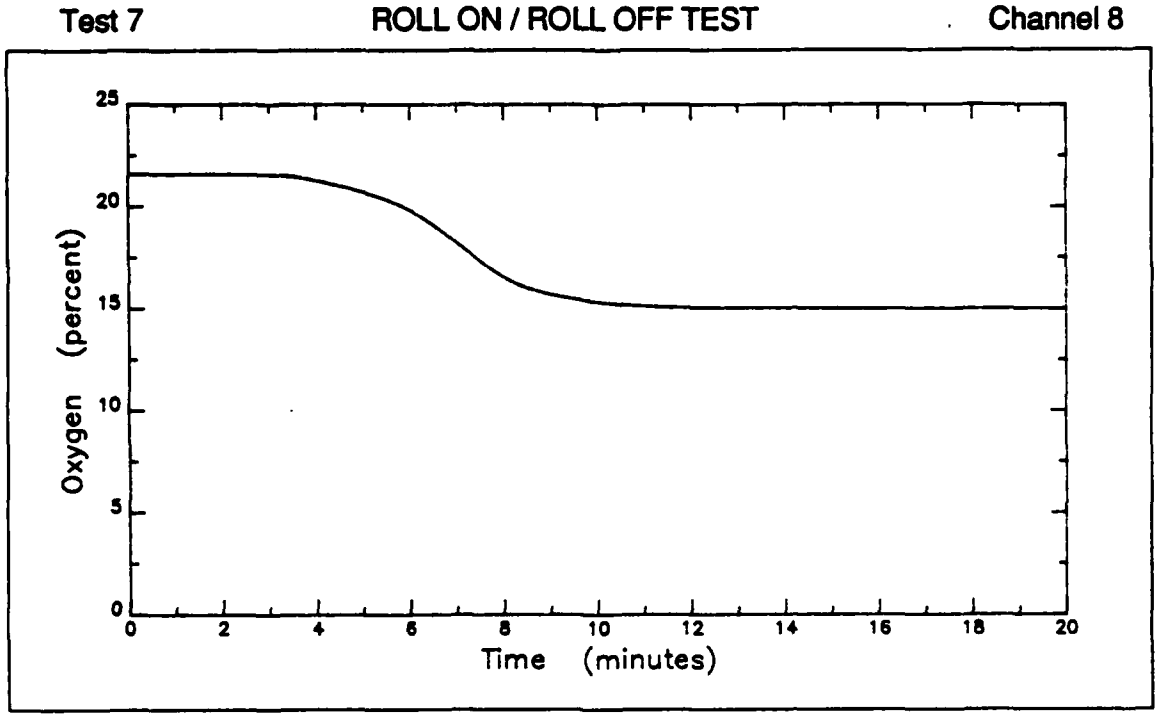

FIGURE B 7-4. Temperature vs Time - Location 10A

TEST 7

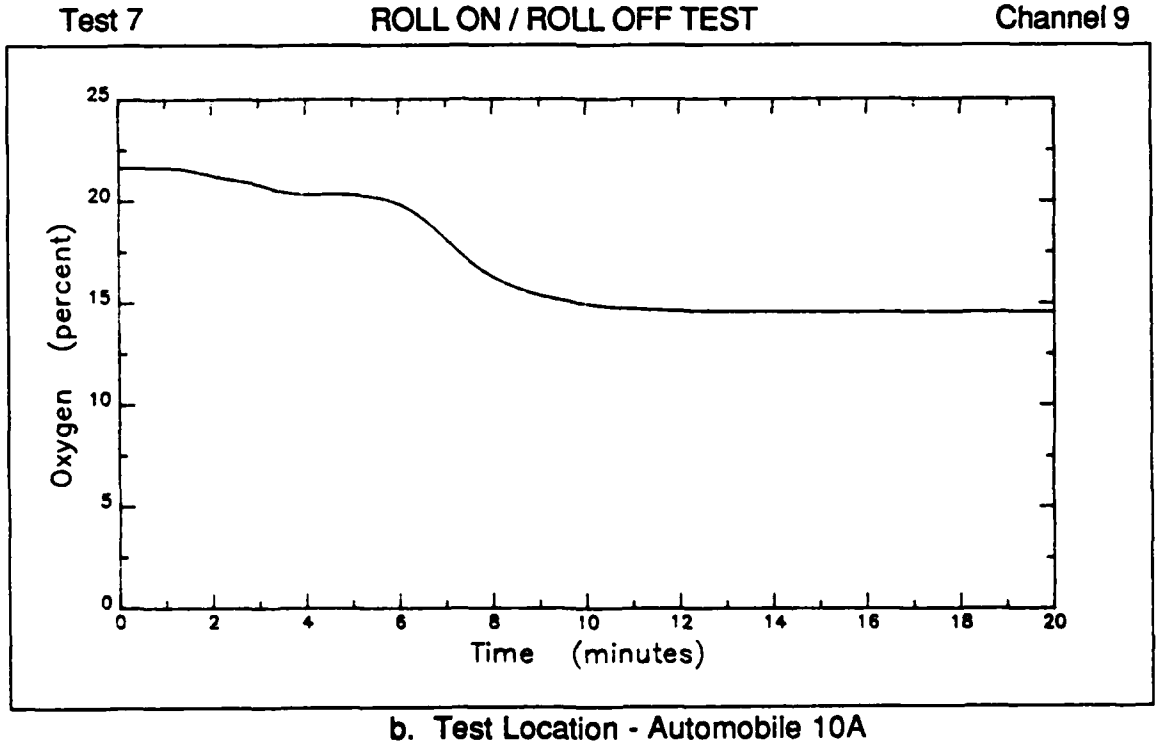
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 7.3 | 17.3 | 15.3 | 15.0 | |
| 9 | Auto 10A | 7.3 | 17.5 | 15.3 | 14.5 | |
| 10 | Auto 12A | 7.3 | 16.4 | 15.3 | 14.4 | |
| 11 | Auto 11A | 7.3 | 16.3 | 11.8 | 15.9 | |
| 12 | Auto 9B | 7.3 | 16.0 | 10.5 | 15.8 | |
| 13 | Auto 12B | 7.3 | 17.7 | 10.8 | 17.3 | |
| | | AVERAGE | 16.8 | 11.0 | 15.5 | |



FIGURE B 7-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

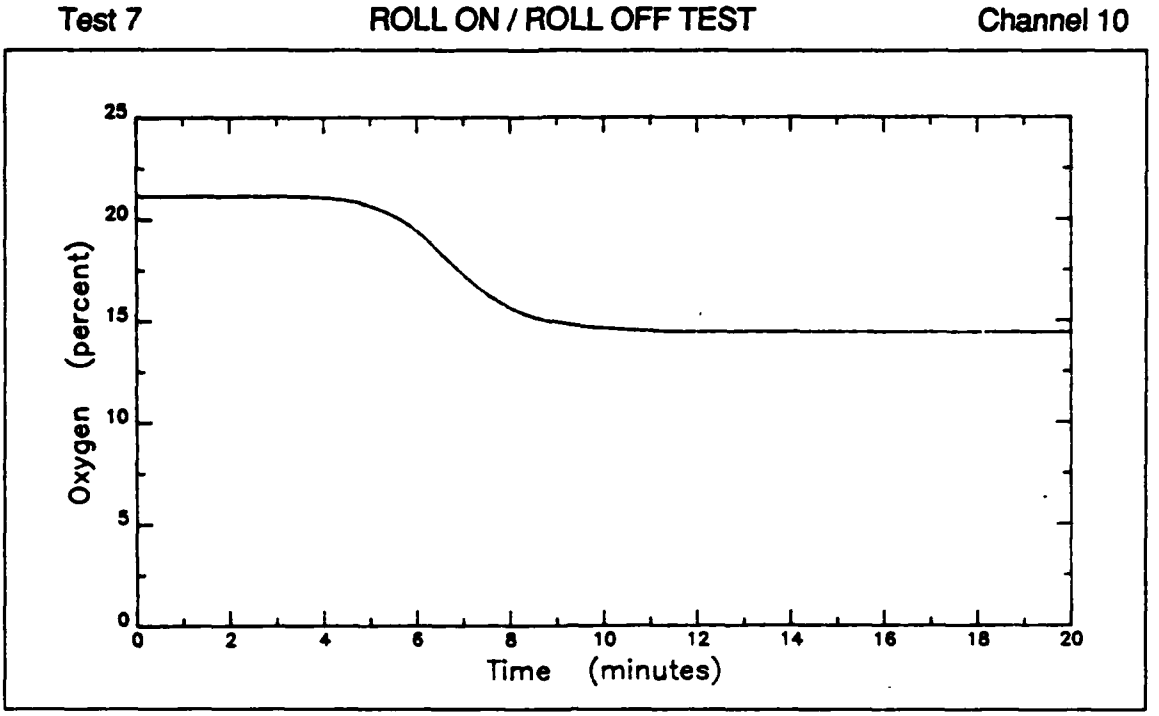



a. Test Location - Automobile 9A

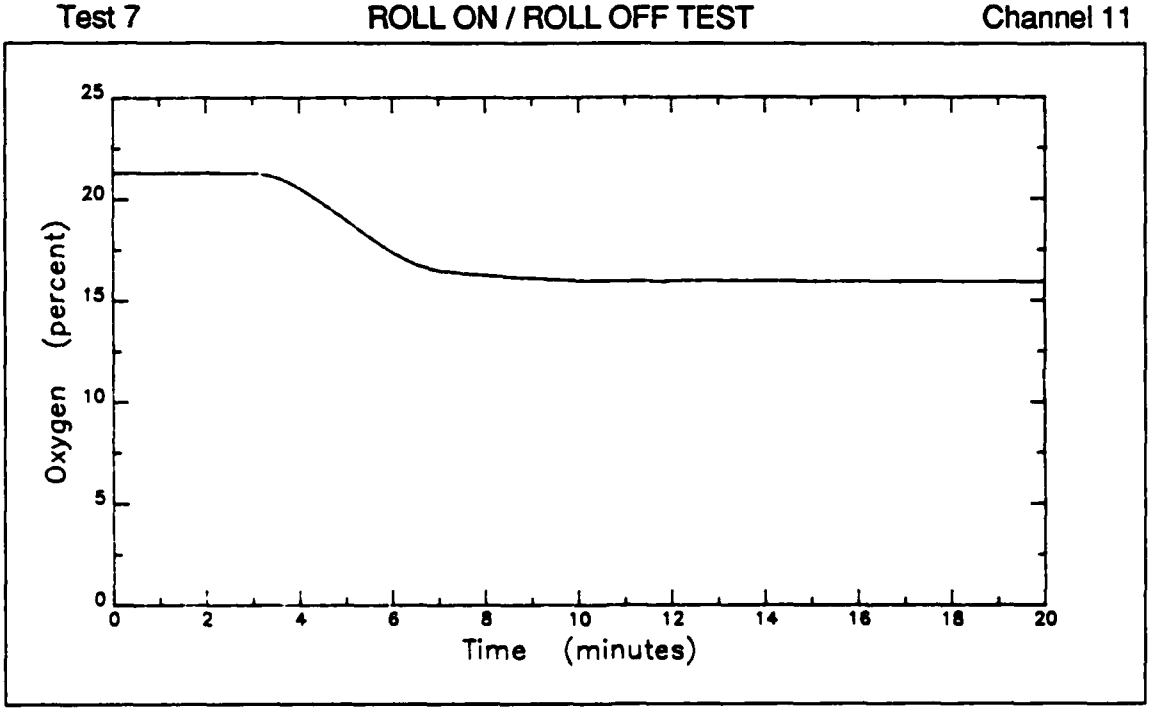



b. Test Location - Automobile 10A

**FIGURE B 7-6. PERCENT OXYGEN vs TIME**

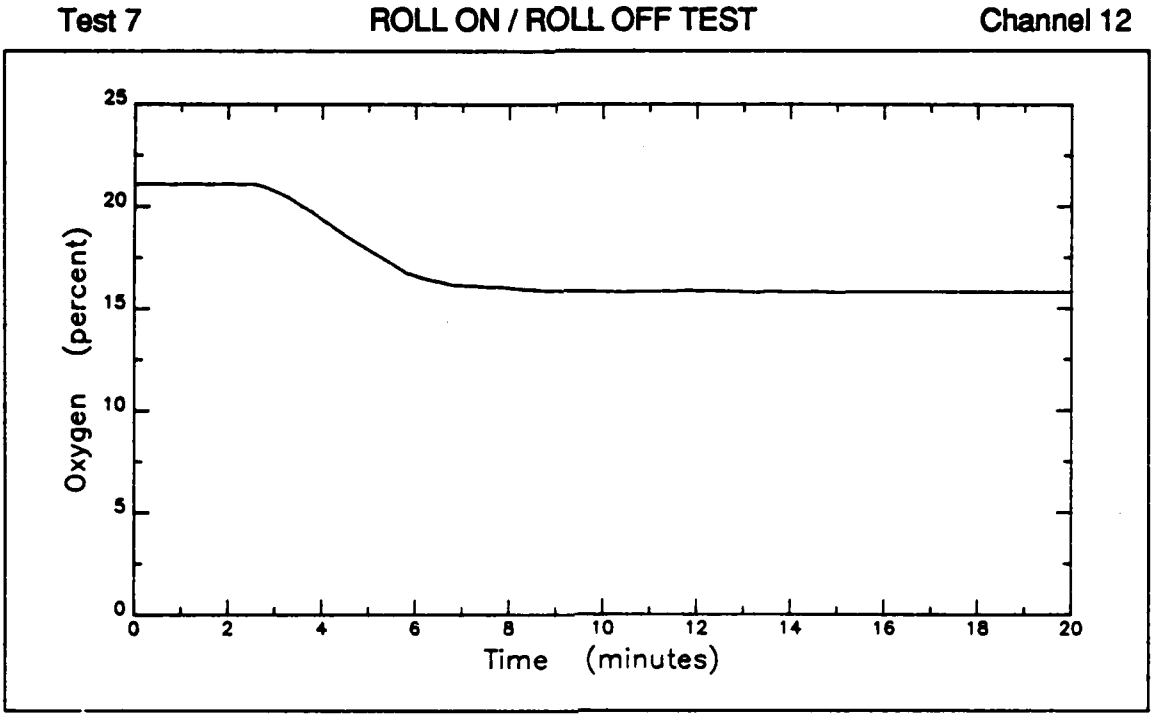



c. Test Location - Automobile 11A

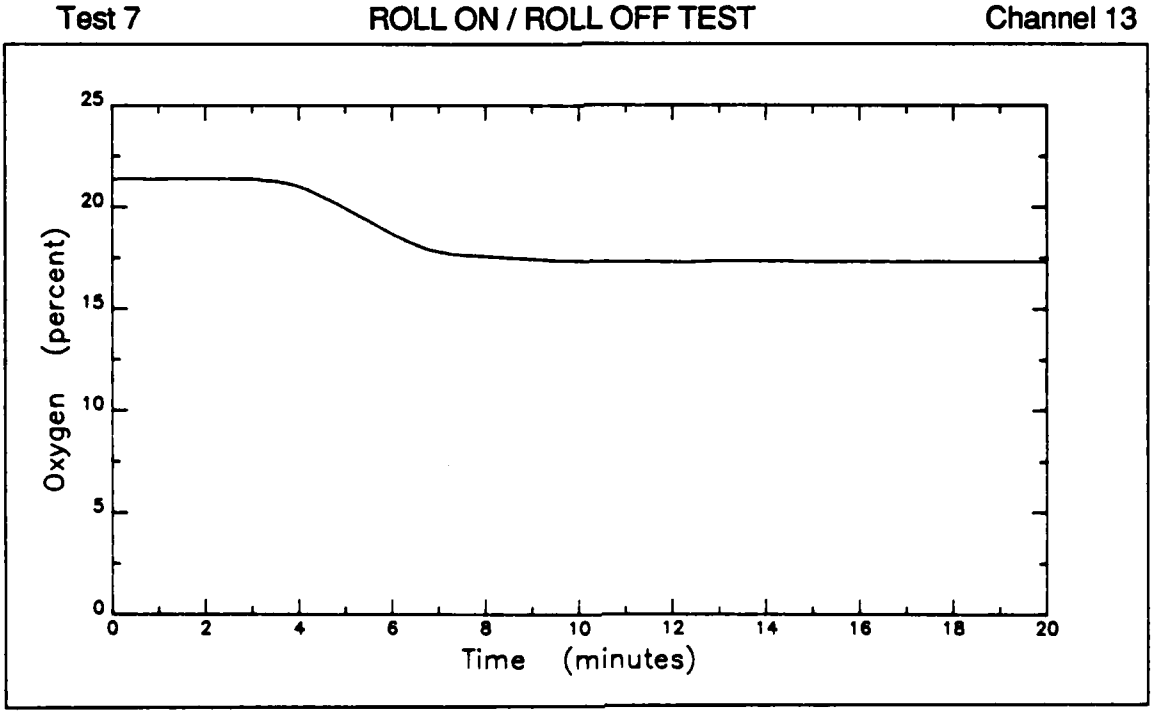



d. Test Location - Automobile 12A

**FIGURE B 7-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test Location - Automobile 9B




f. Test Location - Automobile 12B

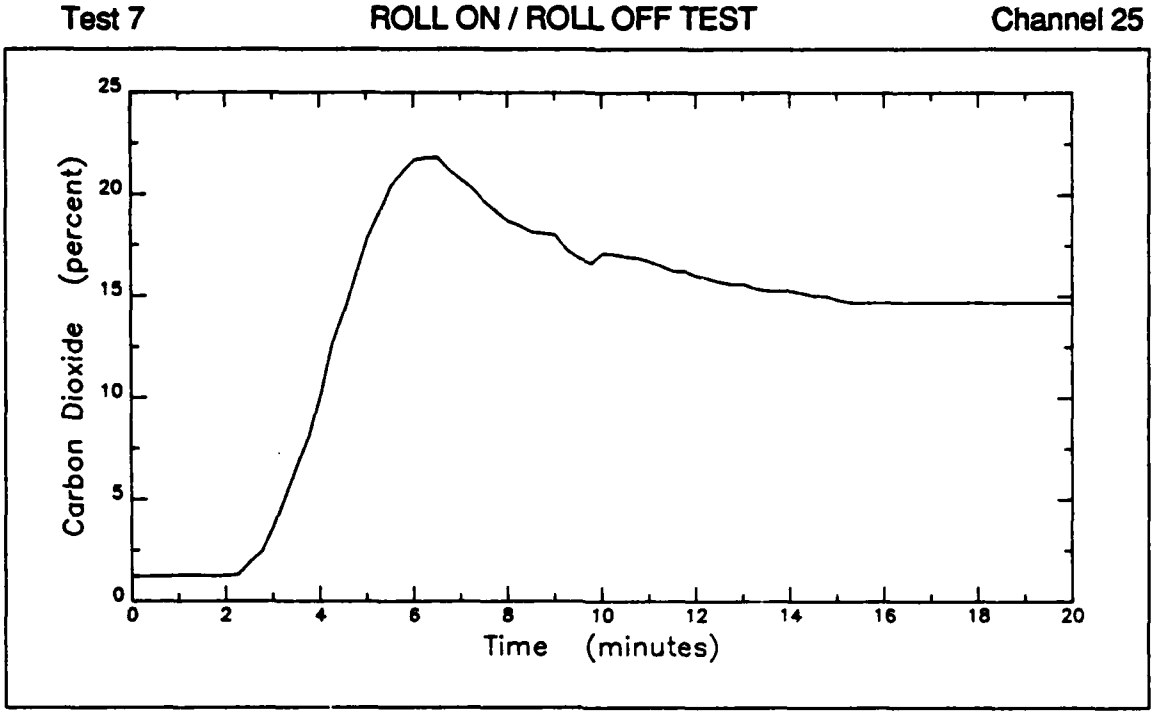
**FIGURE B 7-6. PERCENT OXYGEN vs TIME (cont'd)**

TEST 7

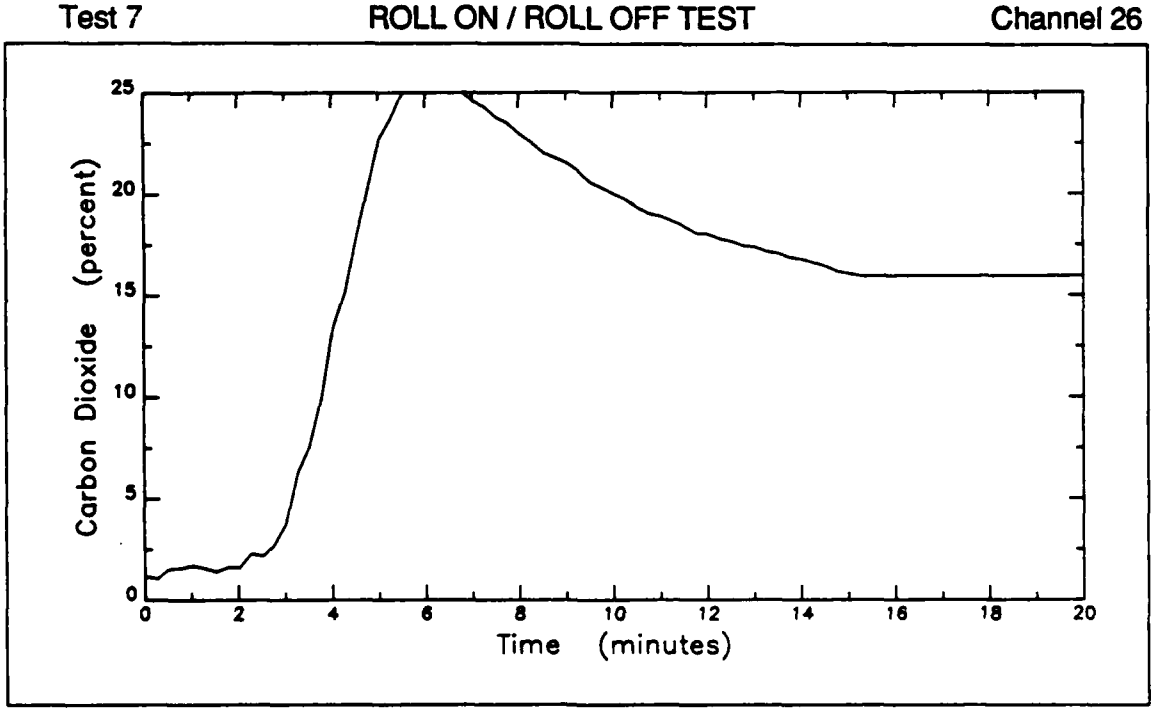
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 7.3 | 20.0 | 6.5 | 21.8 | |
| 26 | Auto 10A | 7.3 | 23.9 | 6.3 | 26.5 | |
| 27 | Auto 11A | 7.3 | 31.2 | 9.8 | 32.3 | |
| 28 | Auto 12A | 7.3 | 31.2 | 7.0 | 31.5 | |
| 29 | Auto 9C | 7.3 | 26.2 | 6.8 | 26.9 | |
| 30 | Auto 3A | 7.3 | 22.9 | 7.3 | 22.9 | |
| 31 | Auto 9B | 7.3 | 31.3 | 9.8 | 32.8 | |
| 32 | Auto 12B | 7.3 | 25.5 | 15.2 | 32.8 | |
| 33 | Auto 3B | 7.3 | 24.9 | 8.0 | 25.1 | |
| | | AVERAGE | 26.3 | 7.7 | 27.5 | |



FIGURE B 7-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

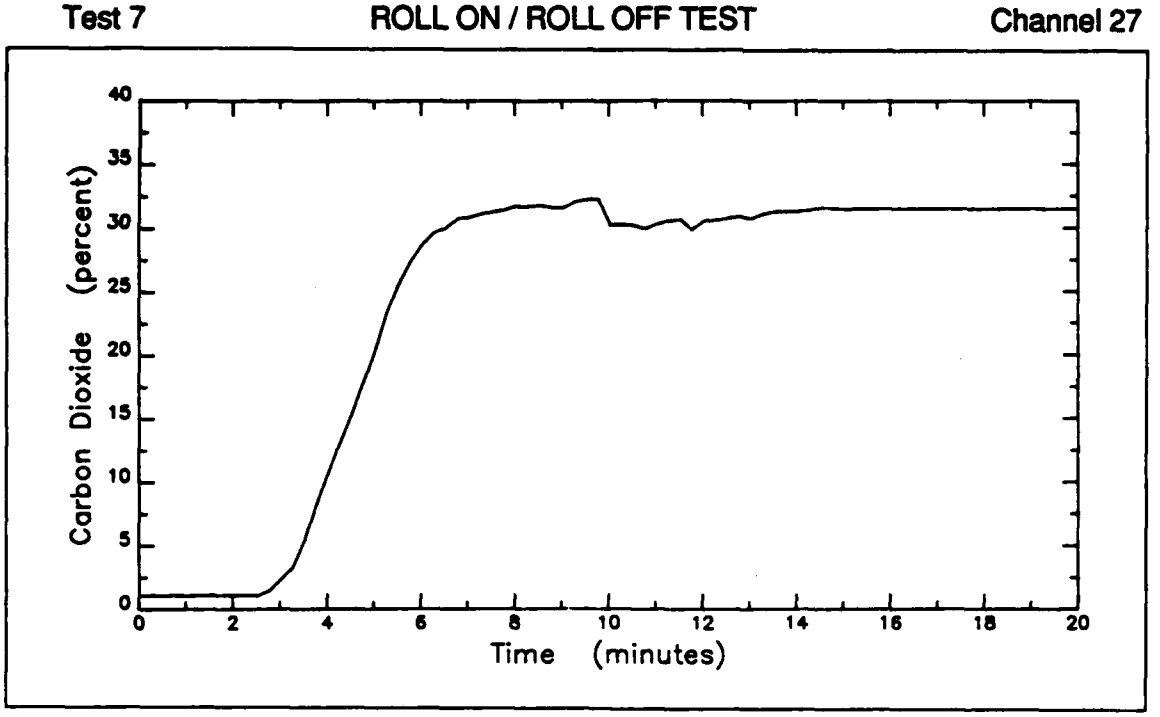



a. Test location - Automobile 9A

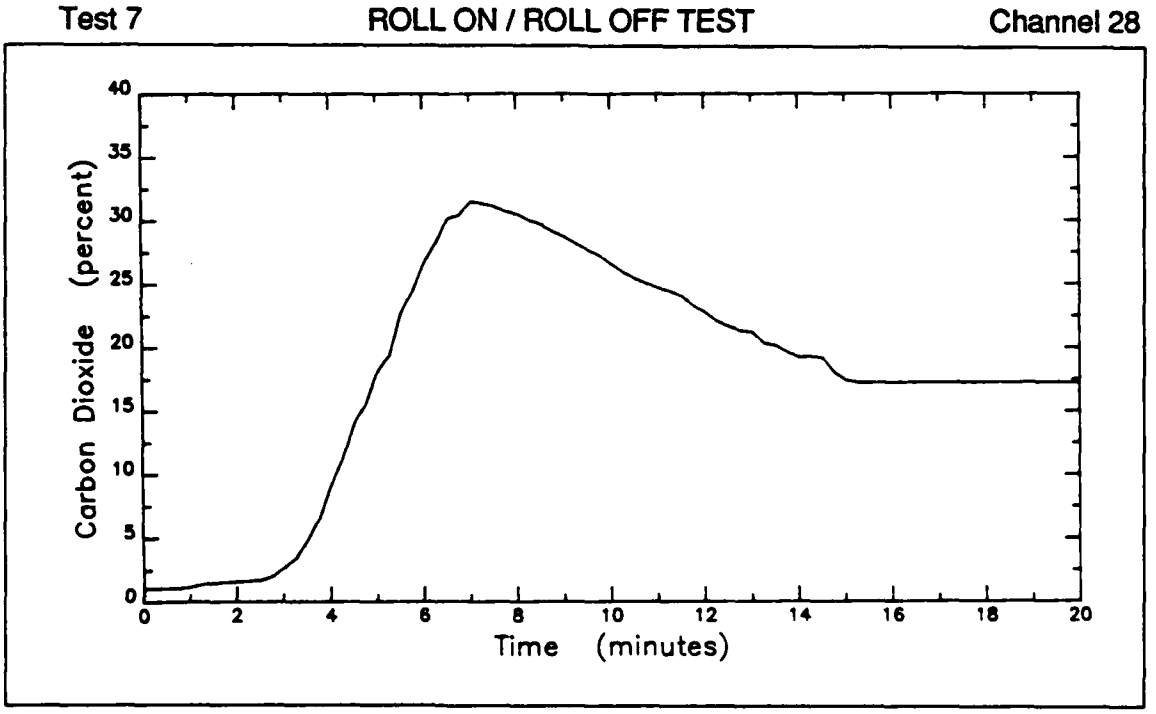



b. Test location - Automobile 10A

**FIGURE B 7-8. PERCENT CARBON DIOXIDE vs TIME**

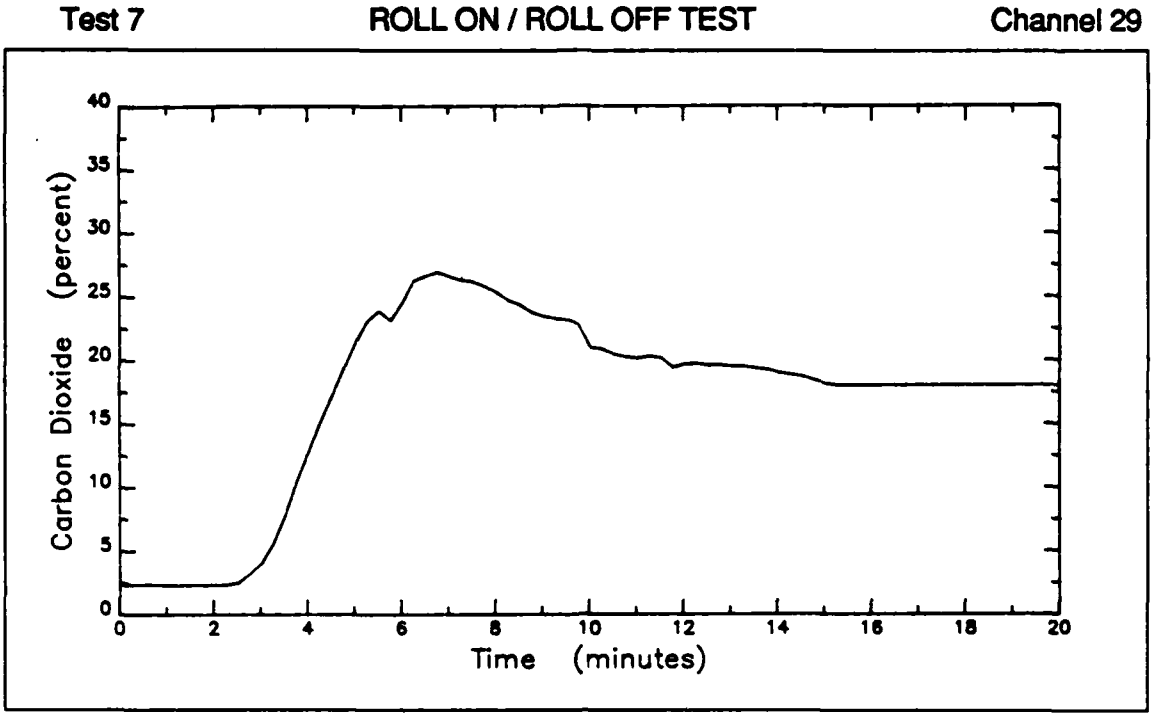



c. Test location - Automobile 11A

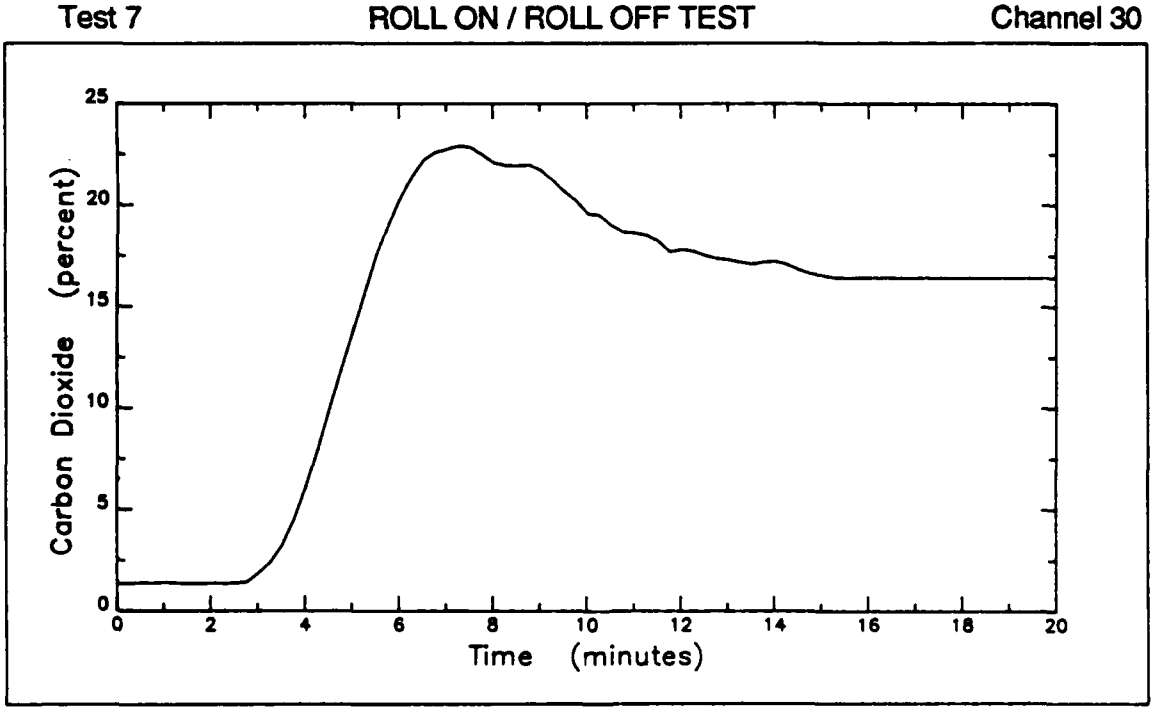



d. Test location - Automobile 12A

**FIGURE B 7-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

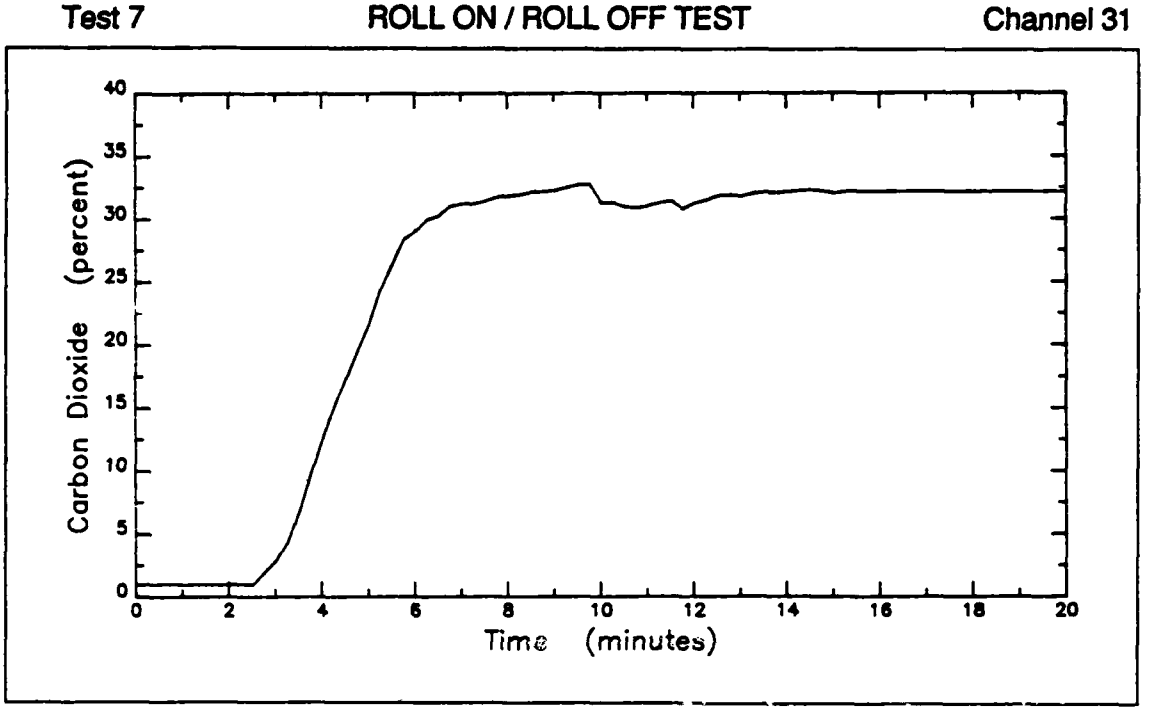



e. Test location - Automobile 9C

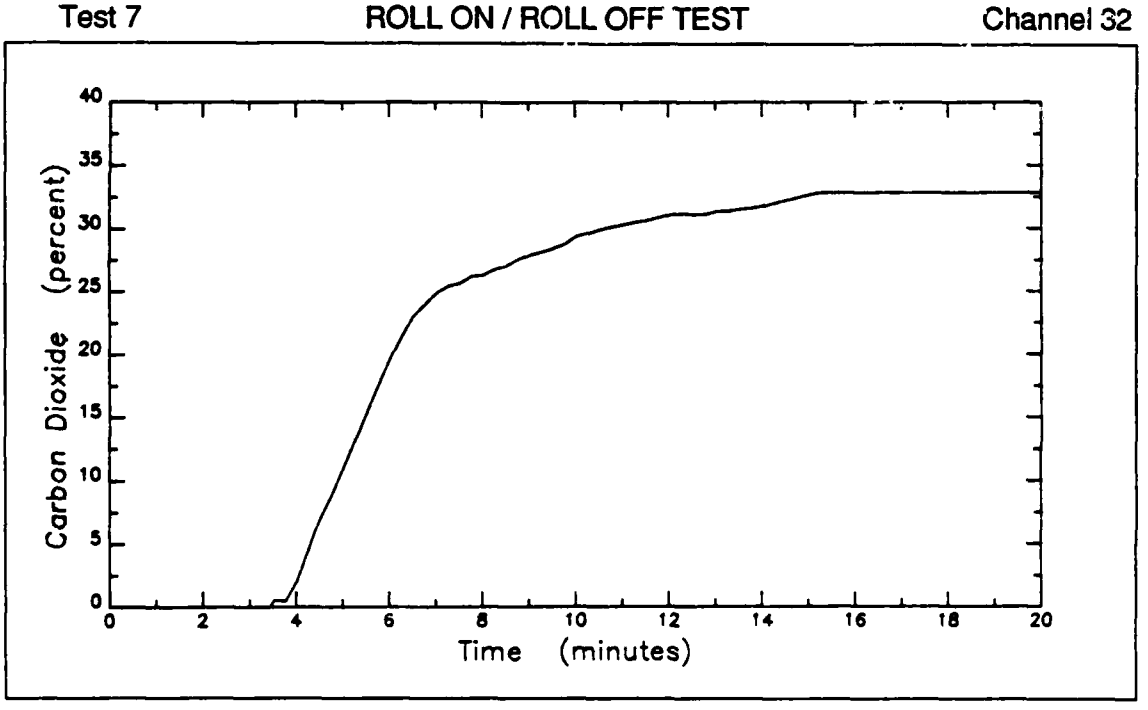



f. Test location - Automobile 3A

**FIGURE B 7-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

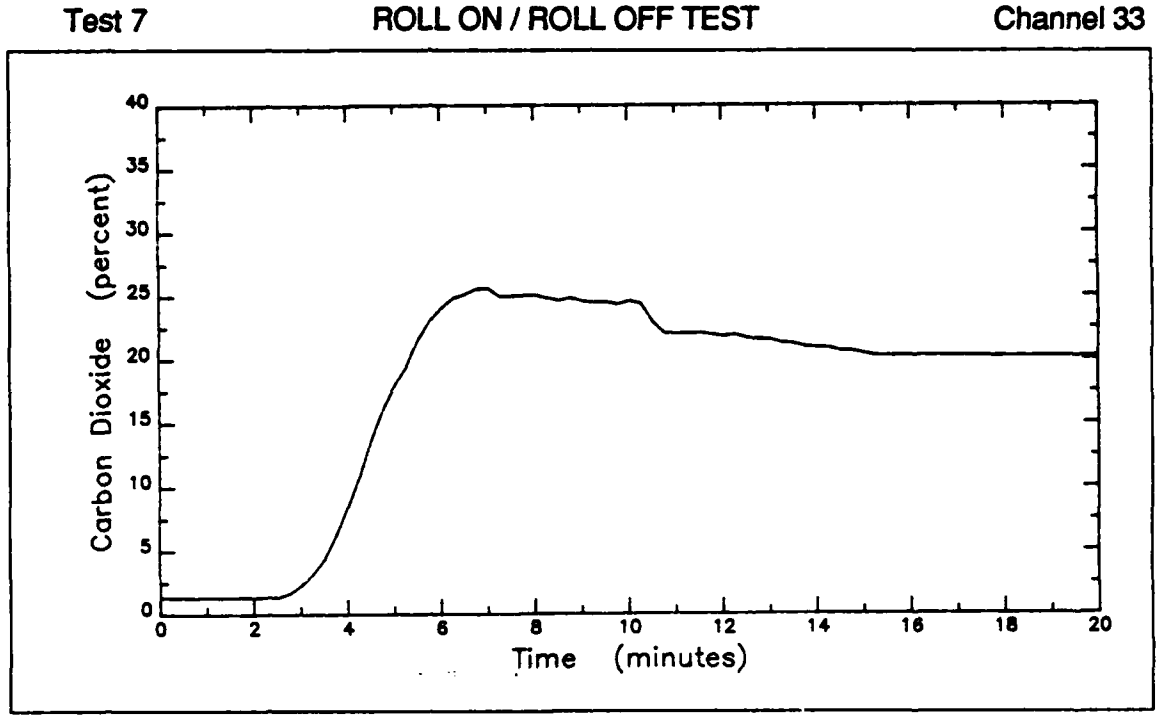



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 7-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

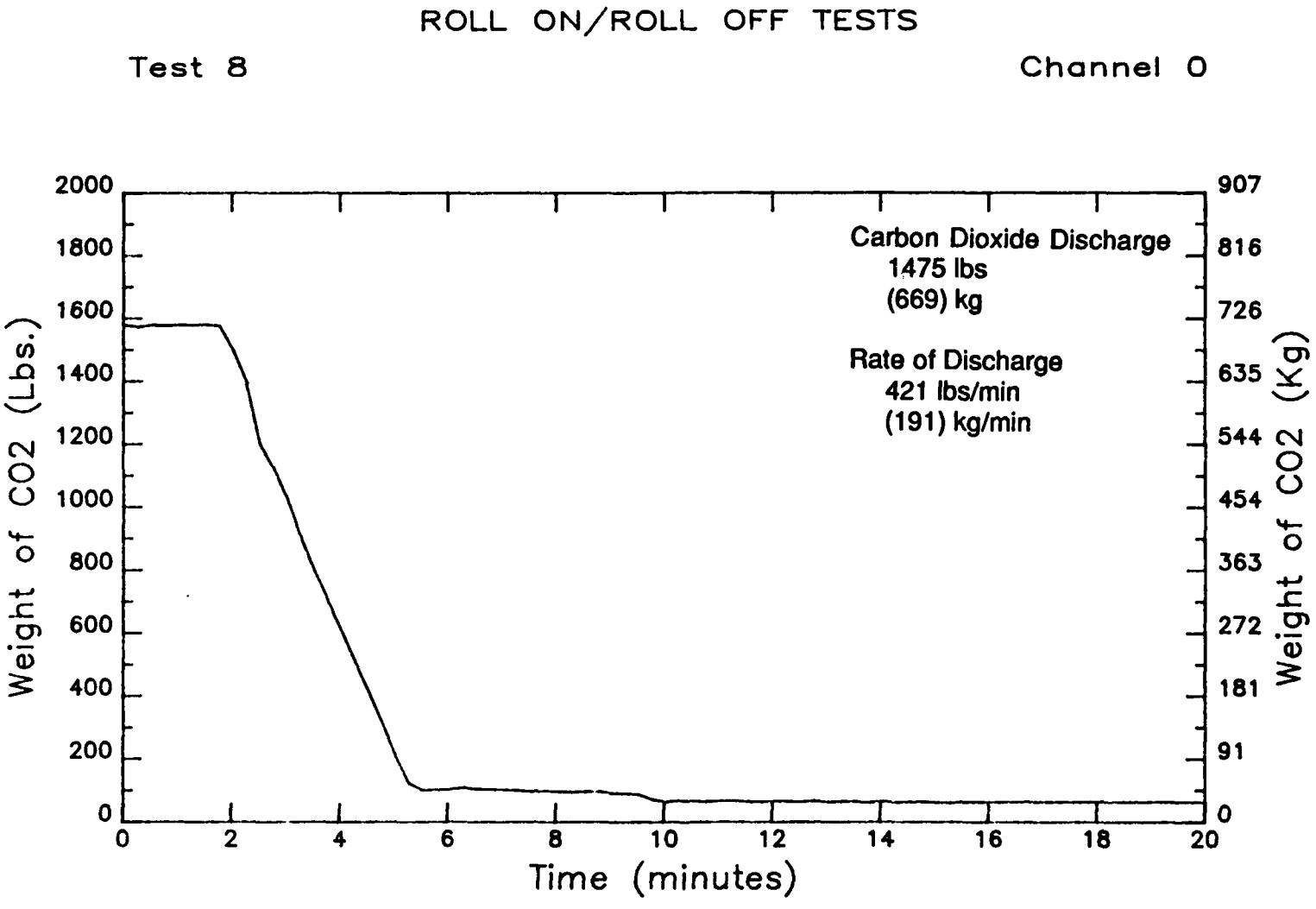



i. Test location - Automobile 3B

**FIGURE B 7-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

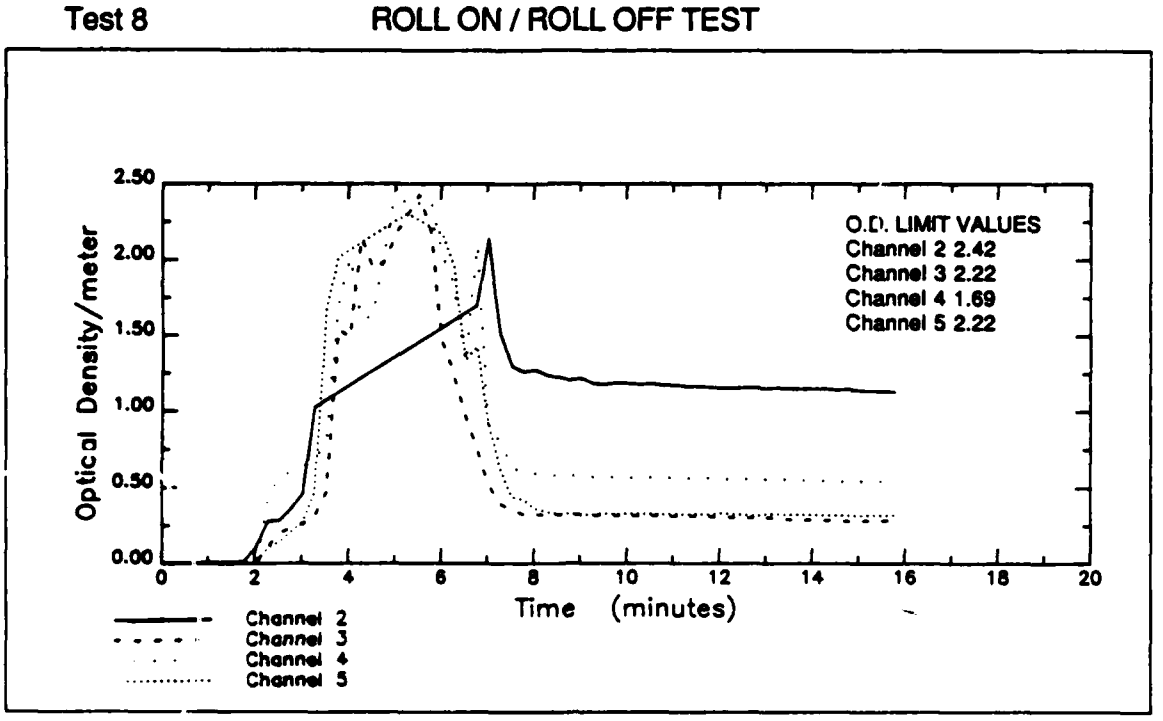
# APPENDIX B

# TEST 8

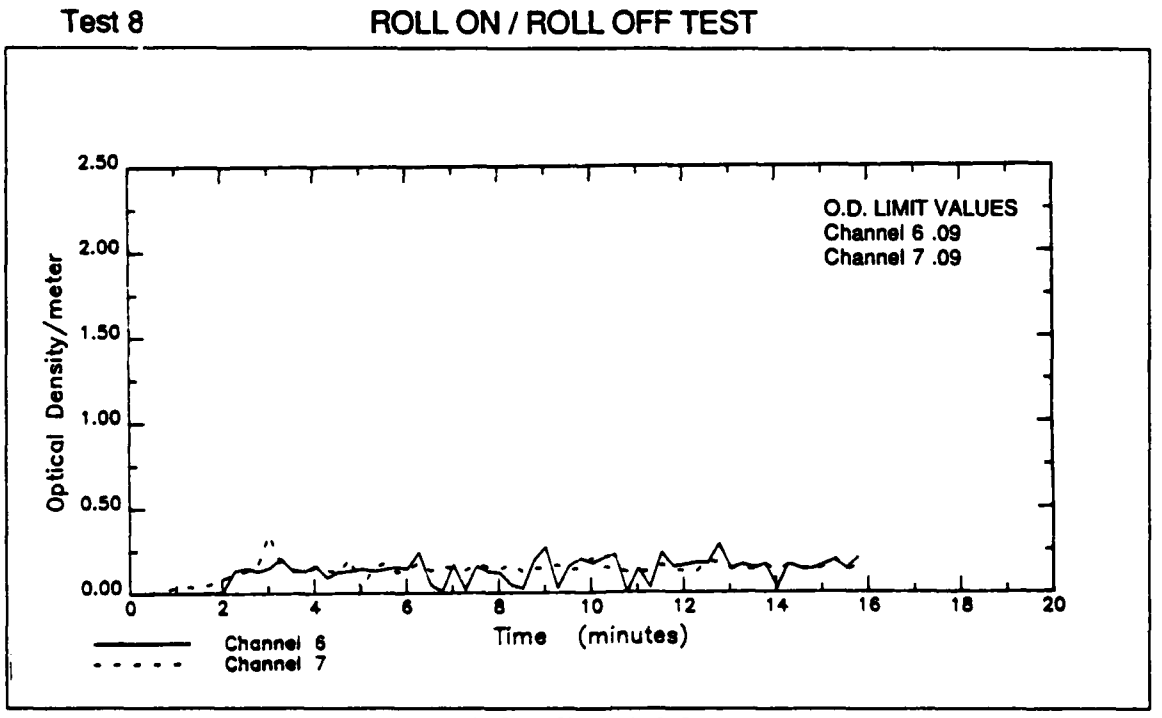



B 8-1

FIGURE B 8-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 8-2. OPTICAL DENSITY vs TIME**

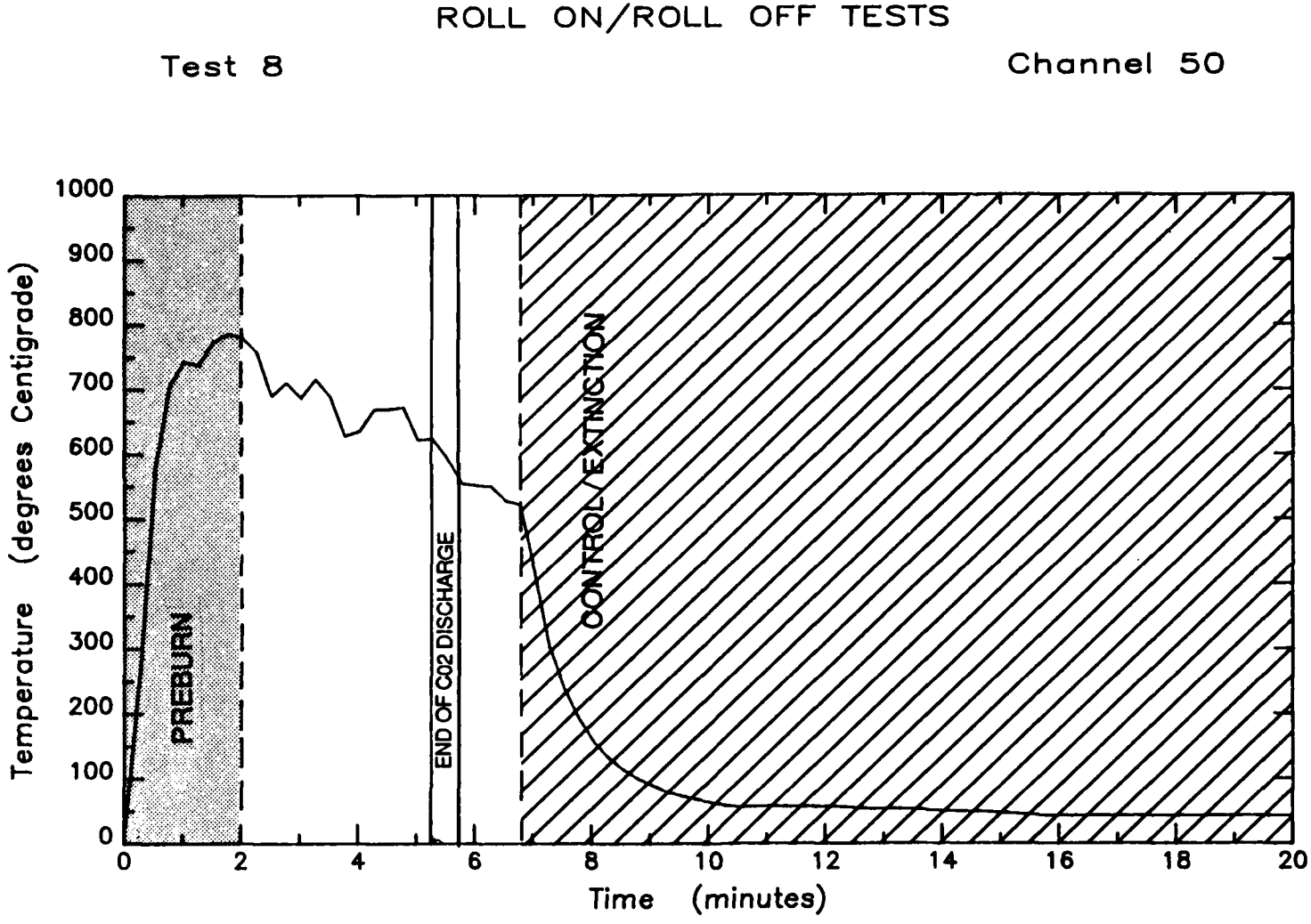
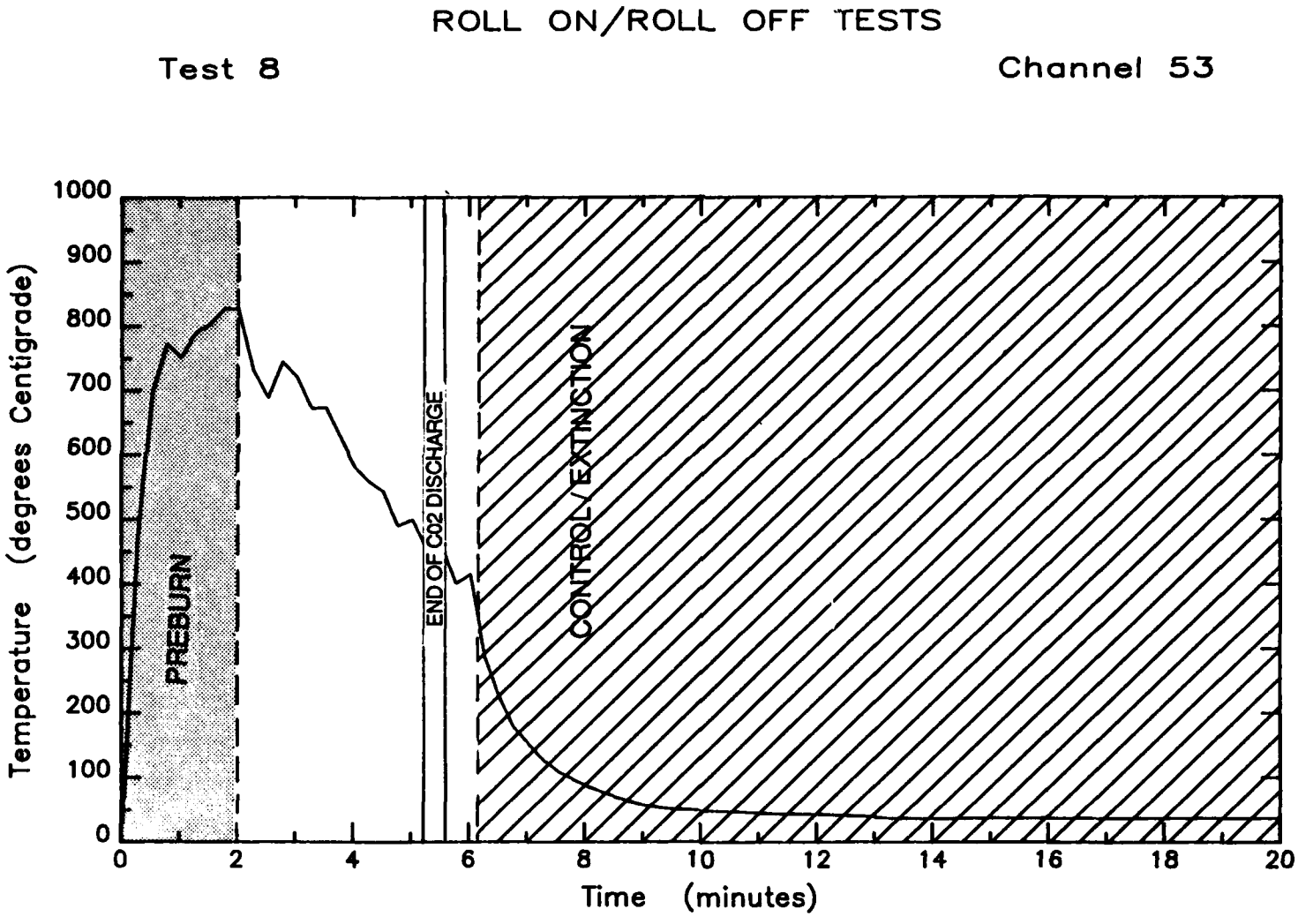



FIGURE B 8-3. Temperature vs Time - Location 9A



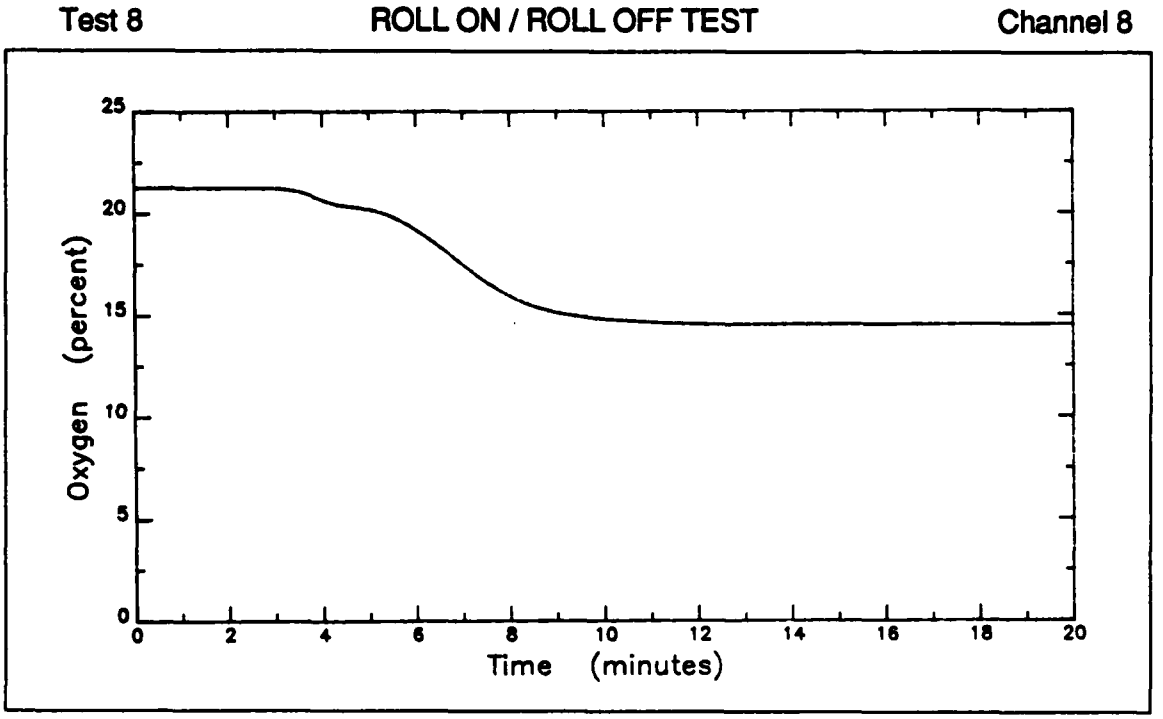

B 8-4

FIGURE B 8-4. Temperature vs Time - Location 10A

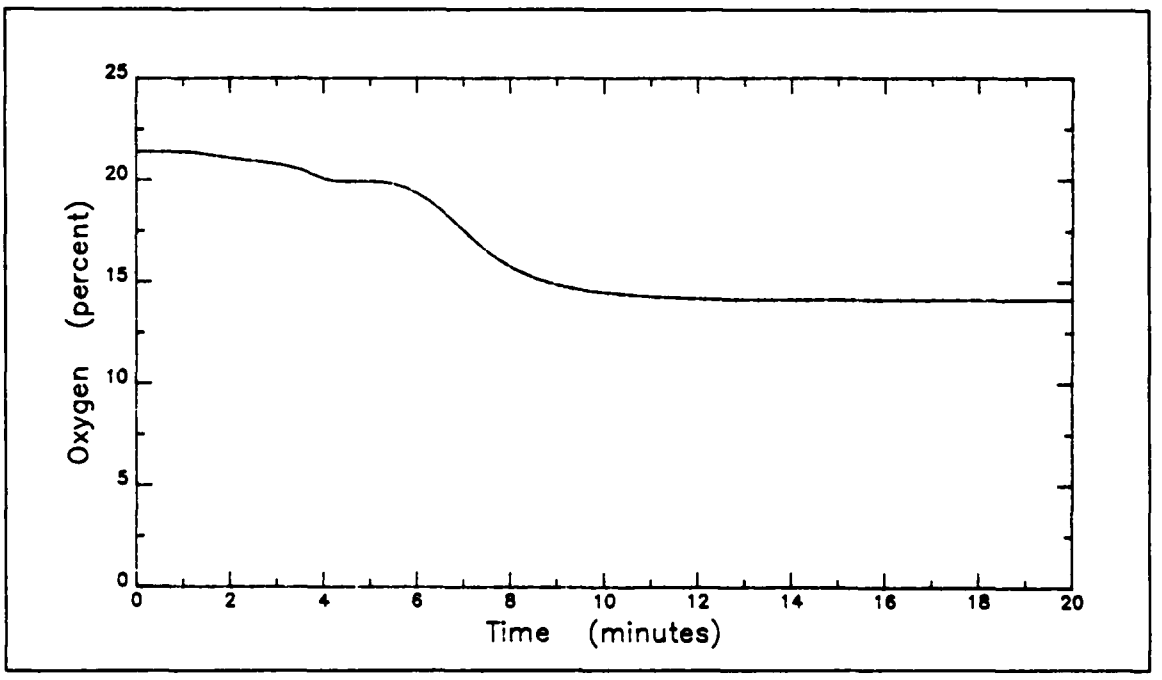
TEST 8

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 7.0 | 17.5 | 15.8 | 14.5 | |
| 9 | Auto 10A | 7.0 | 17.6 | 13.8 | 14.1 | 14.4% OXYGEN @ 10.3 MINUTES |
| 10 | Auto 12A | 7.0 | 17.5 | 13.8 | 14.1 | 14.4% OXYGEN @ 10.1 MINUTES |
| 11 | Auto 11A | 7.0 | 16.2 | 15.0 | 15.5 | |
| 12 | Auto 9B | 7.0 | 17.5 | 12.8 | 16.8 | |
| 13 | Auto 12B | 7.0 | 17.6 | 13.5 | 16.8 | |
| | | AVERAGE | 17.3 | 13.8 | 15.5 | |

FIGURE B 8-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

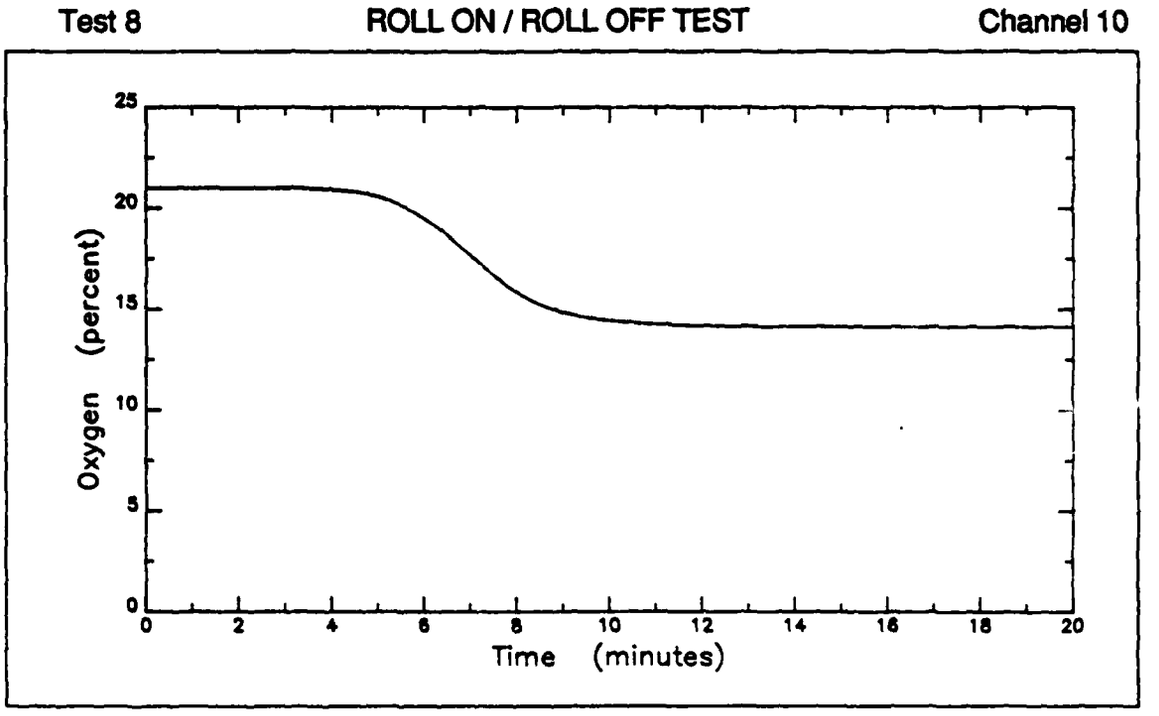



a. Test location - Automobile 9A

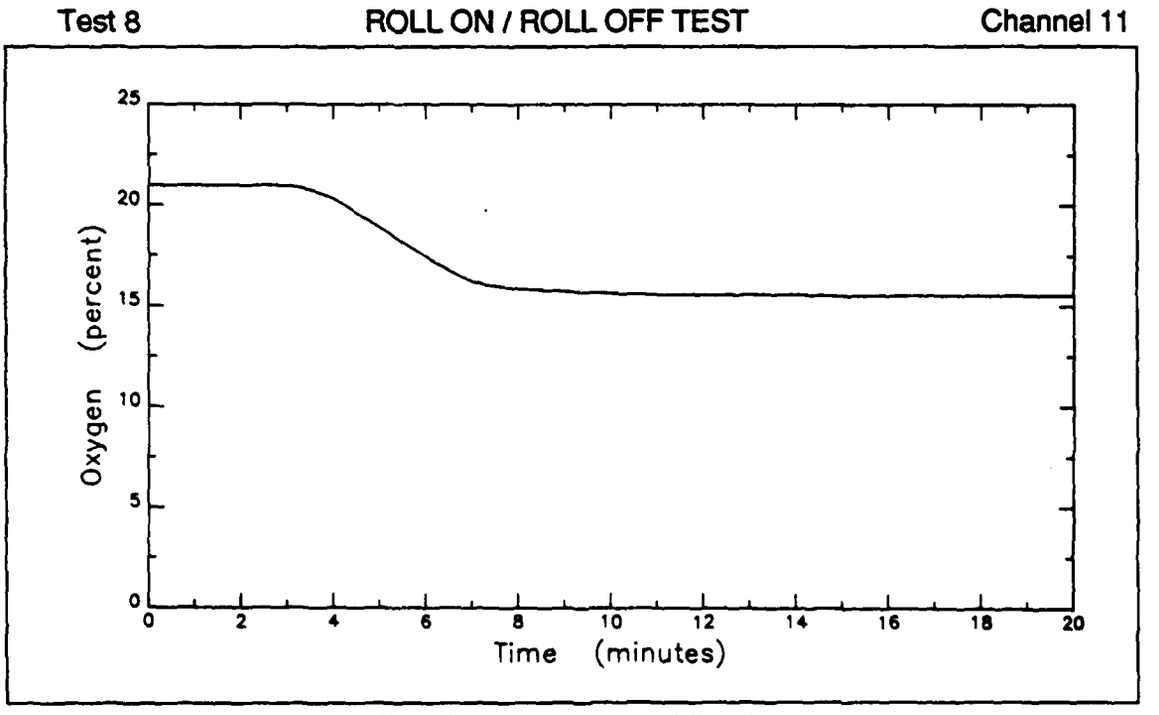



b. Test location - Automobile 10A

**FIGURE B 8-6. PERCENT OXYGEN vs TIME**

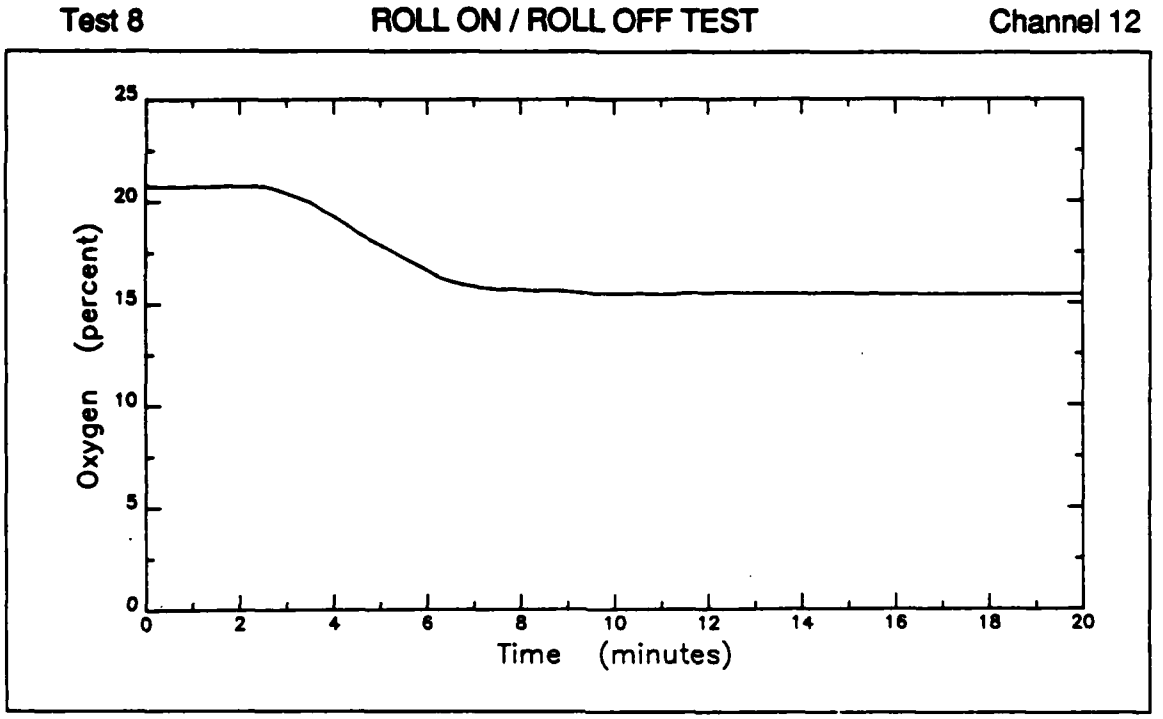



c. Test location - Automobile 11A

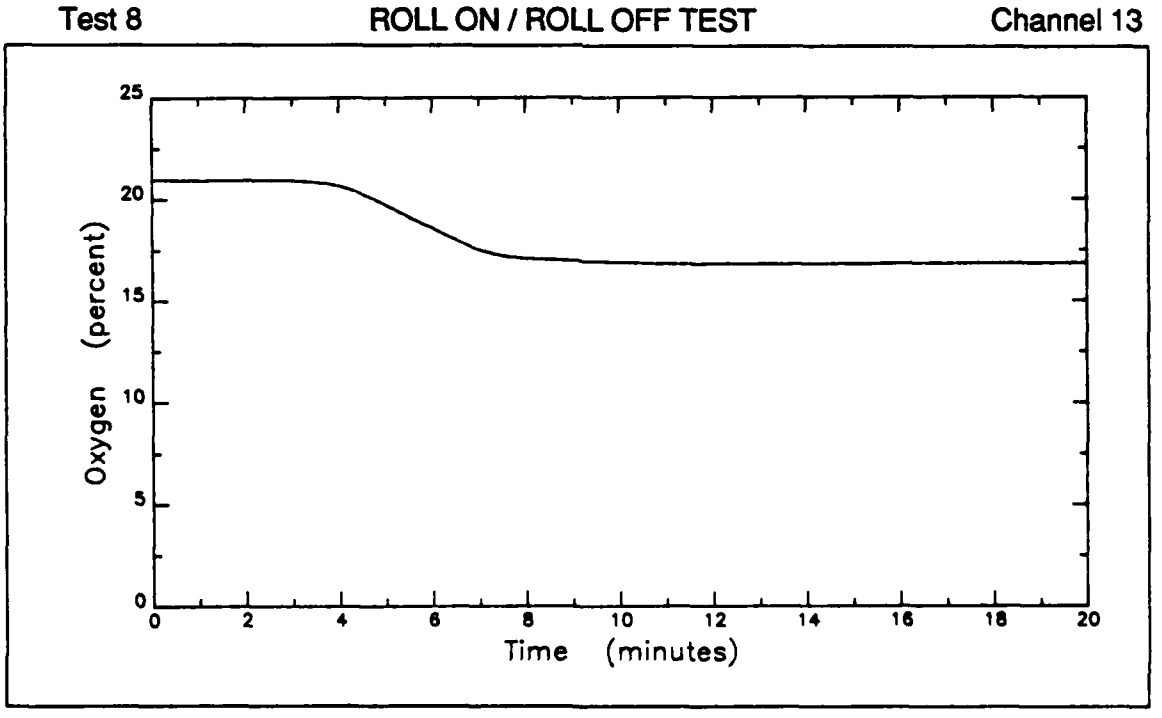



d. Test location - Automobile 12A

**FIGURE B 8-6. PERCENT OXYGEN vs TIME**




e. Test location - Automobile 9B



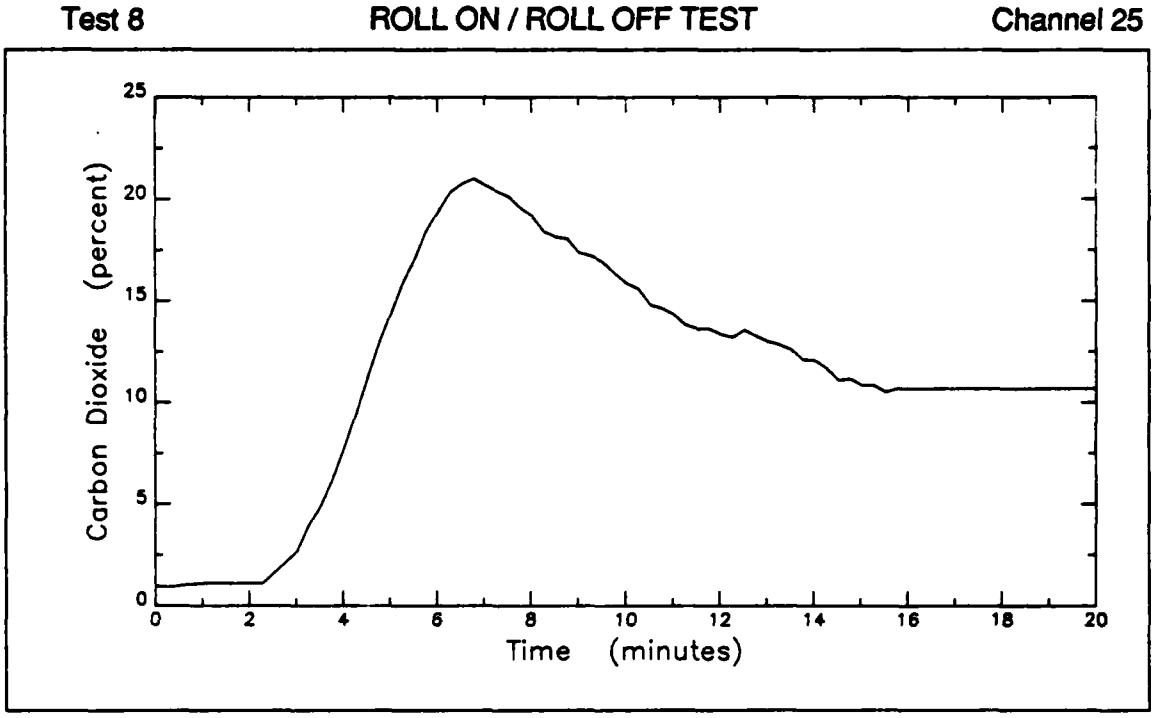

f. Test location - Automobile 12B

**FIGURE B 8-6. PERCENT OXYGEN vs TIME (cont'd)**

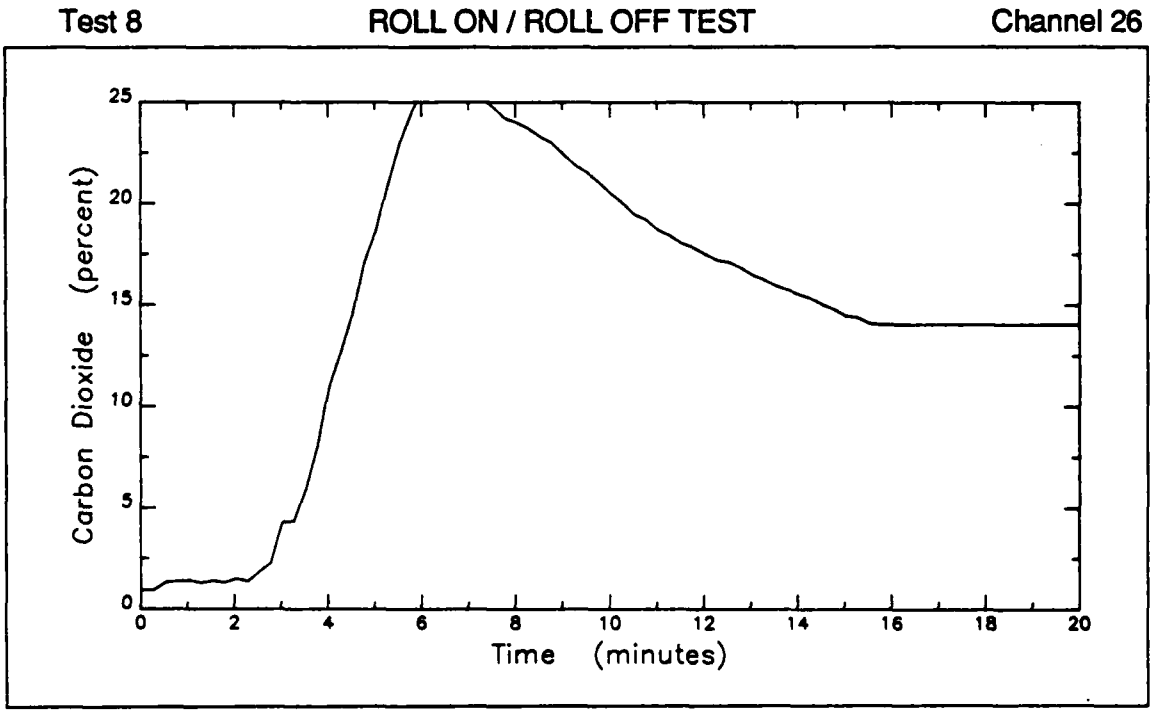
TEST 8

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 7.0 | 20.8 | 6.8 | 21.0 | |
| 26 | Auto 10A | 7.0 | 25.6 | 6.8 | 25.9 | |
| 27 | Auto 11A | 7.0 | 31.3 | 15.8 | 39.2 | |
| 28 | Auto 12A | 7.0 | 28.8 | 7.8 | 30.7 | |
| 29 | Auto 9C | 7.0 | 22.7 | 8.3 | 23.1 | |
| 30 | Auto 3A | 7.0 | 20.0 | 7.8 | 20.7 | |
| 31 | Auto 9B | 7.0 | 31.4 | 10.5 | 33.9 | |
| 32 | Auto 12B | 7.0 | 29.0 | 15.8 | 37.8 | |
| 33 | Auto 3B | 7.0 | 29.6 | 8.0 | 24.7 | |
| | | AVERAGE | 26.0 | 8.0 | 25.7 | |

FIGURE B 8-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

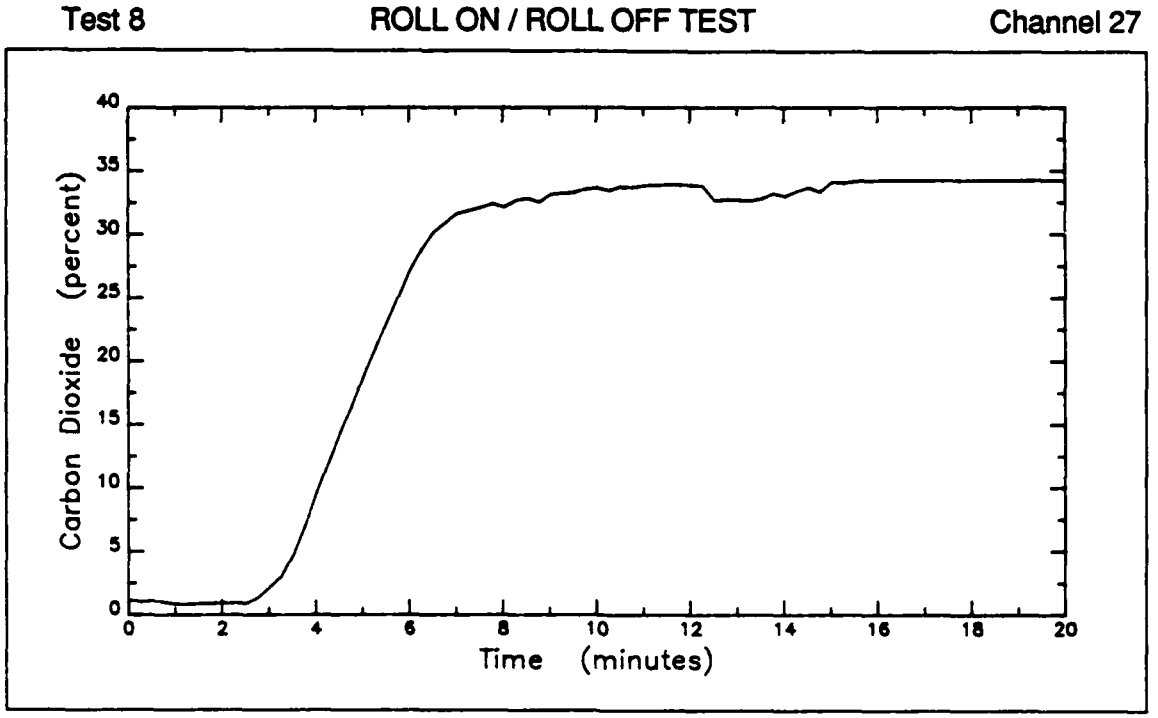



a. Test location - Automobile 9A

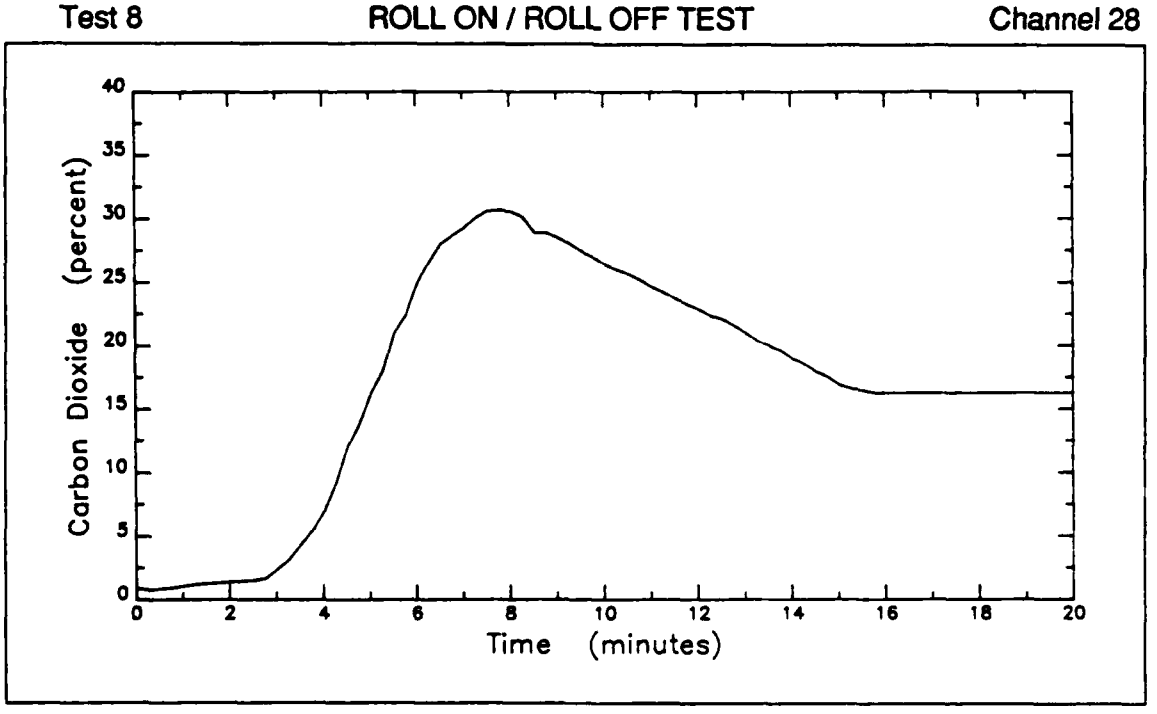



b. Test location - Automobile 10A

**FIGURE B 8-8. PERCENT CARBON DIOXIDE vs TIME**

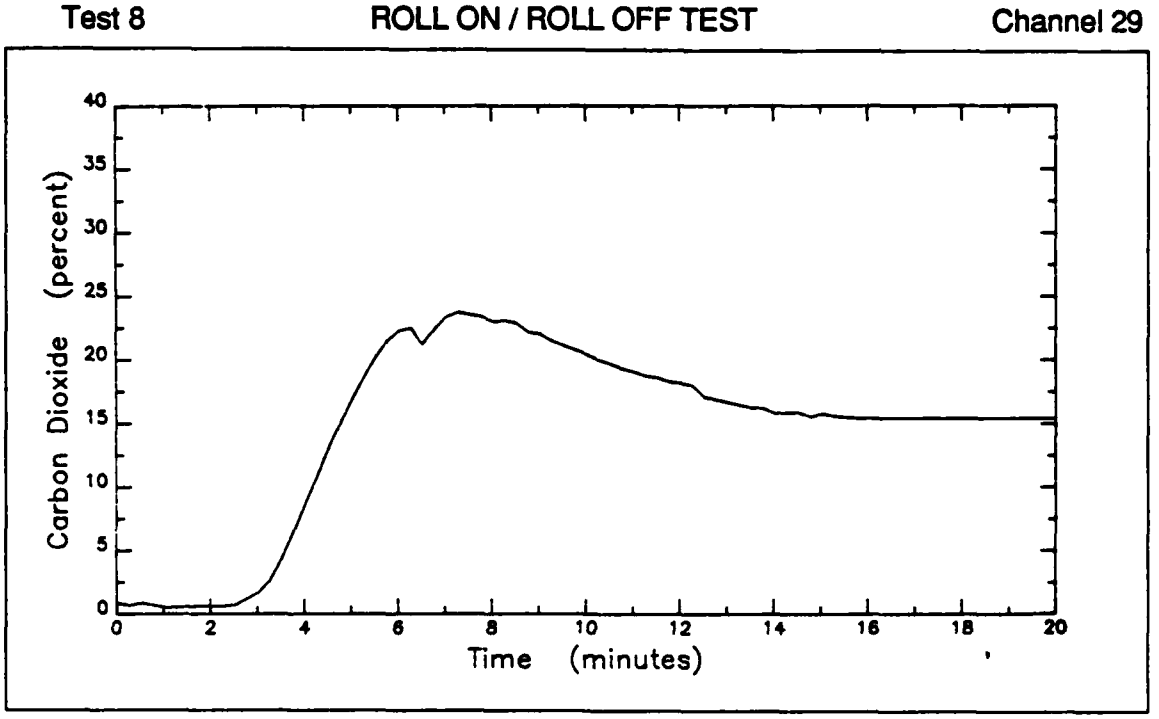



c. Test location - Automobile 11A

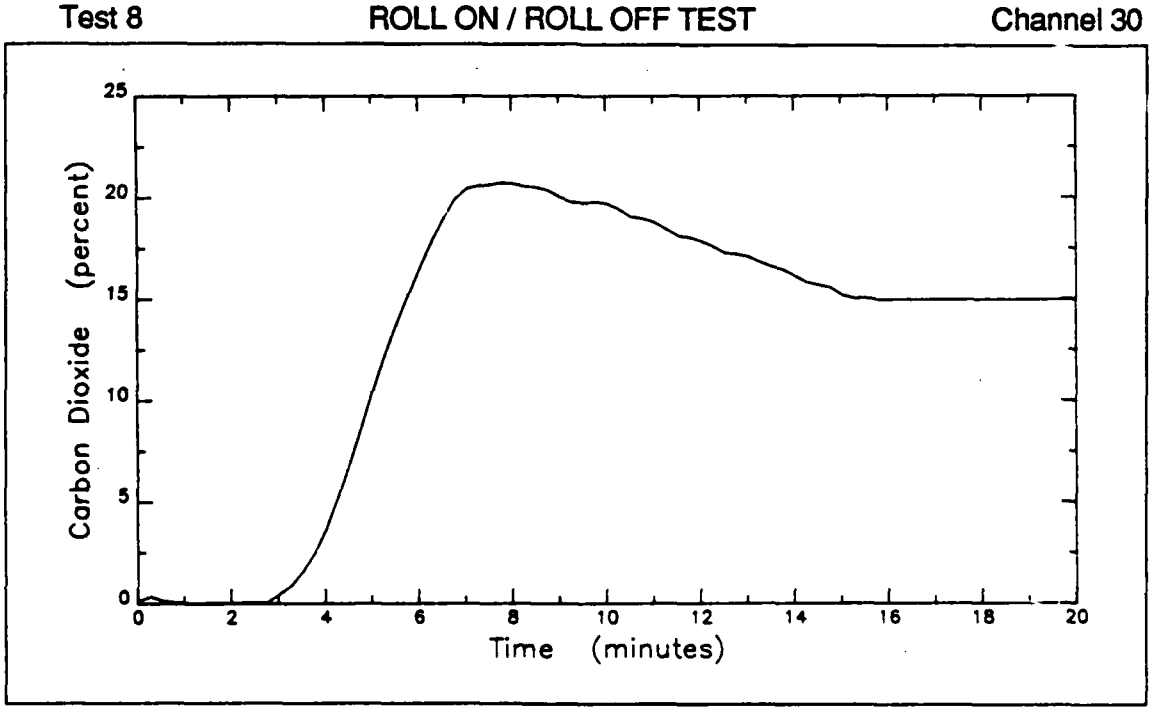



d. Test location - Automobile 12A

**FIGURE B 8-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

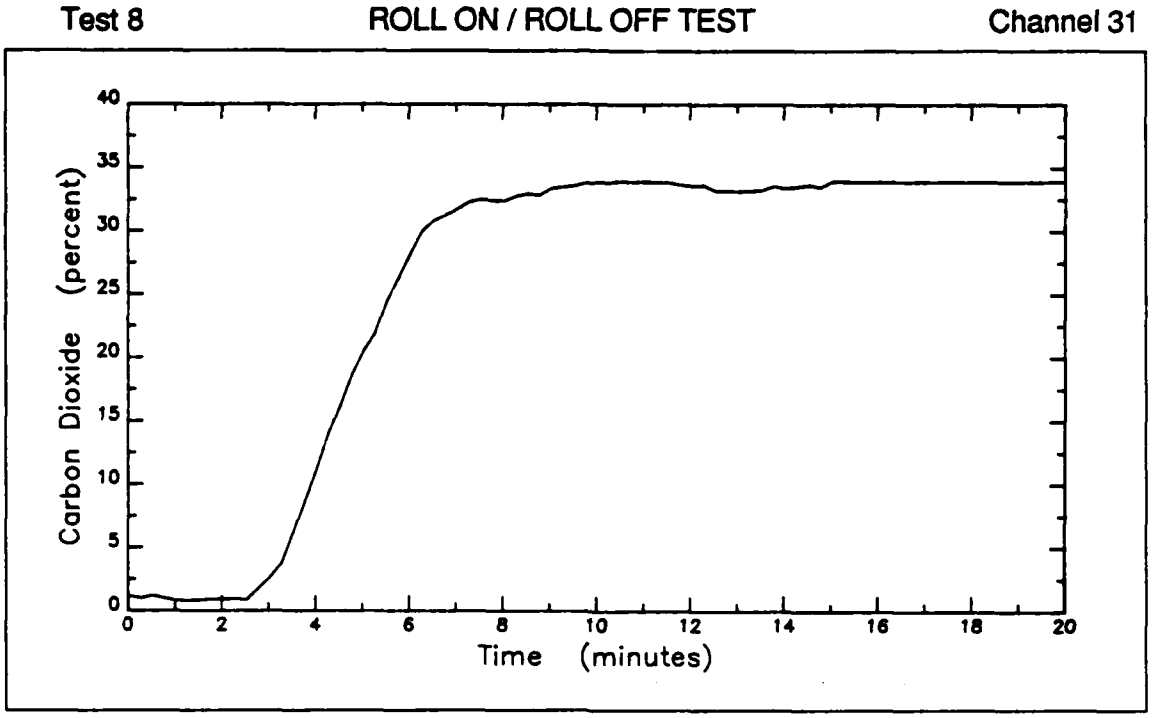



e. Test location - Automobile 9C

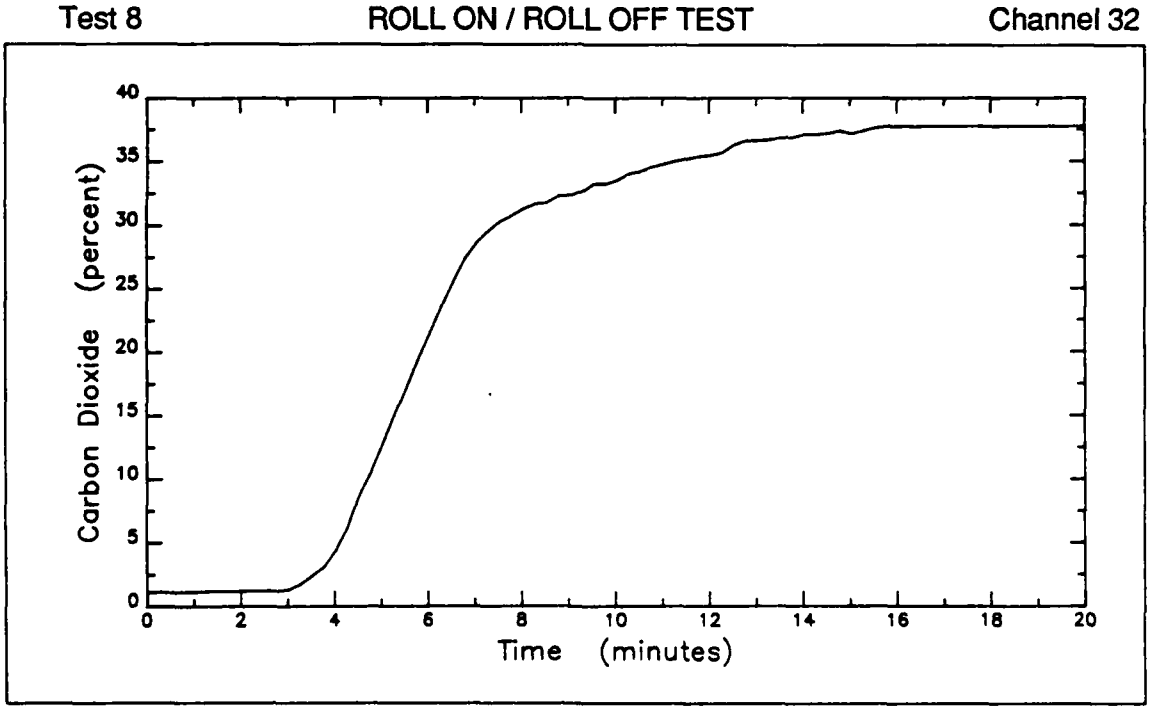



f. Test location - Automobile 3A

**FIGURE B 8-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

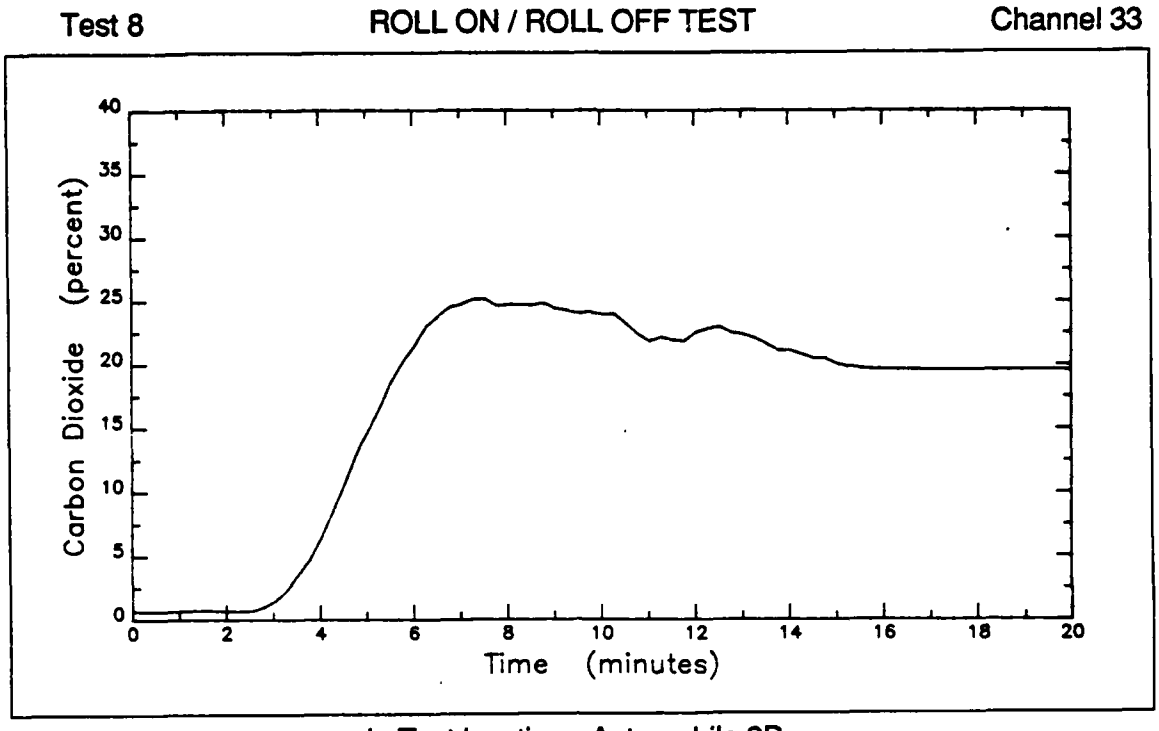



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 8-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 8-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

# TEST 9

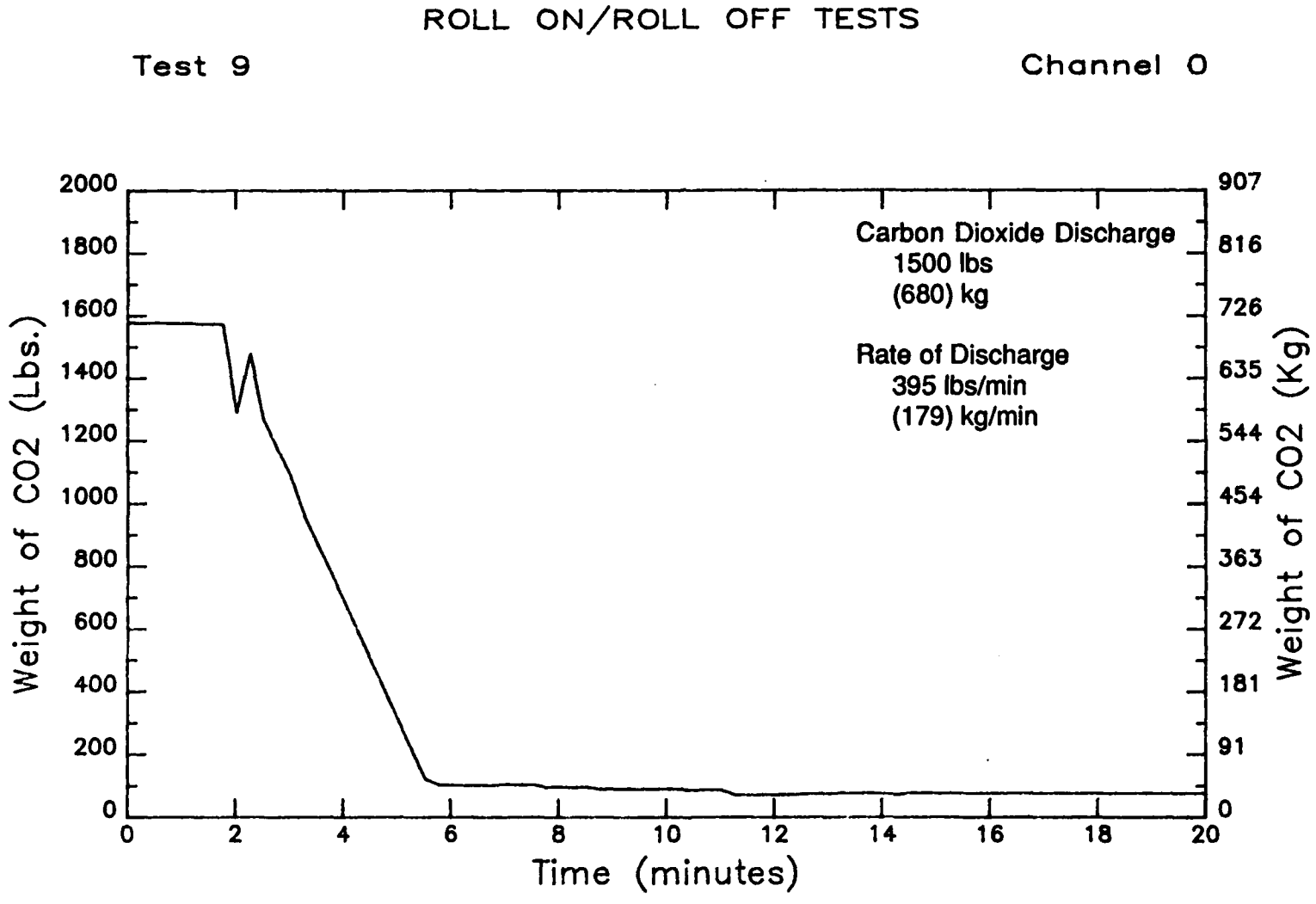
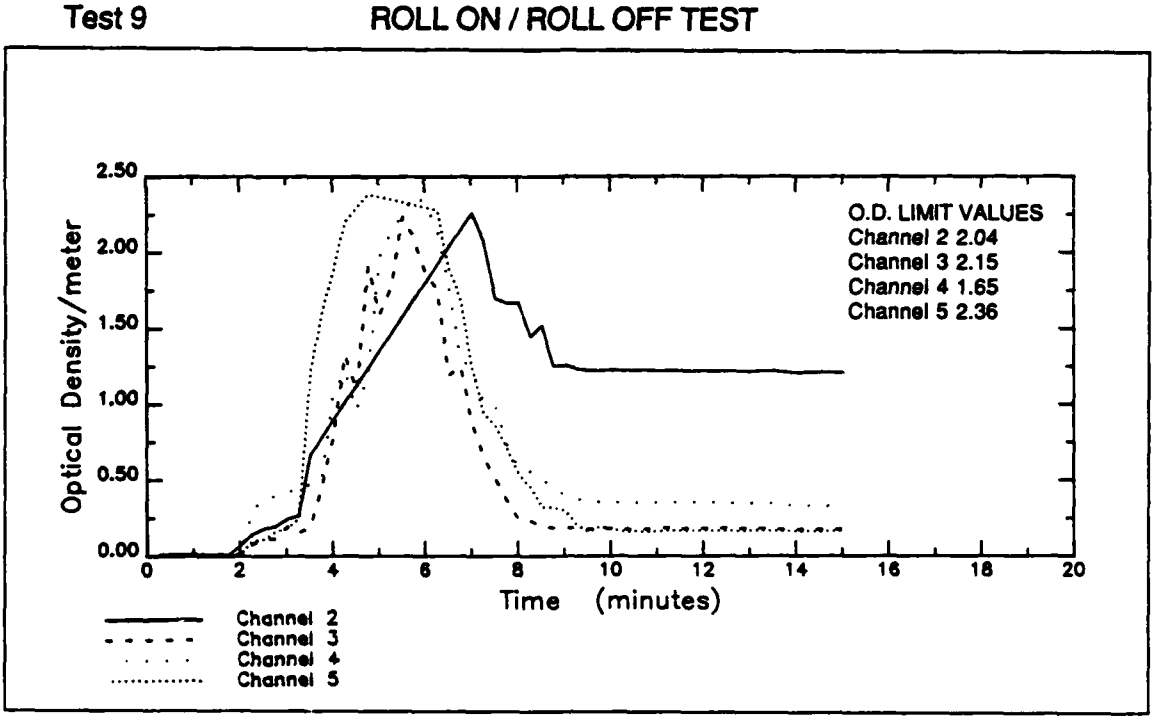
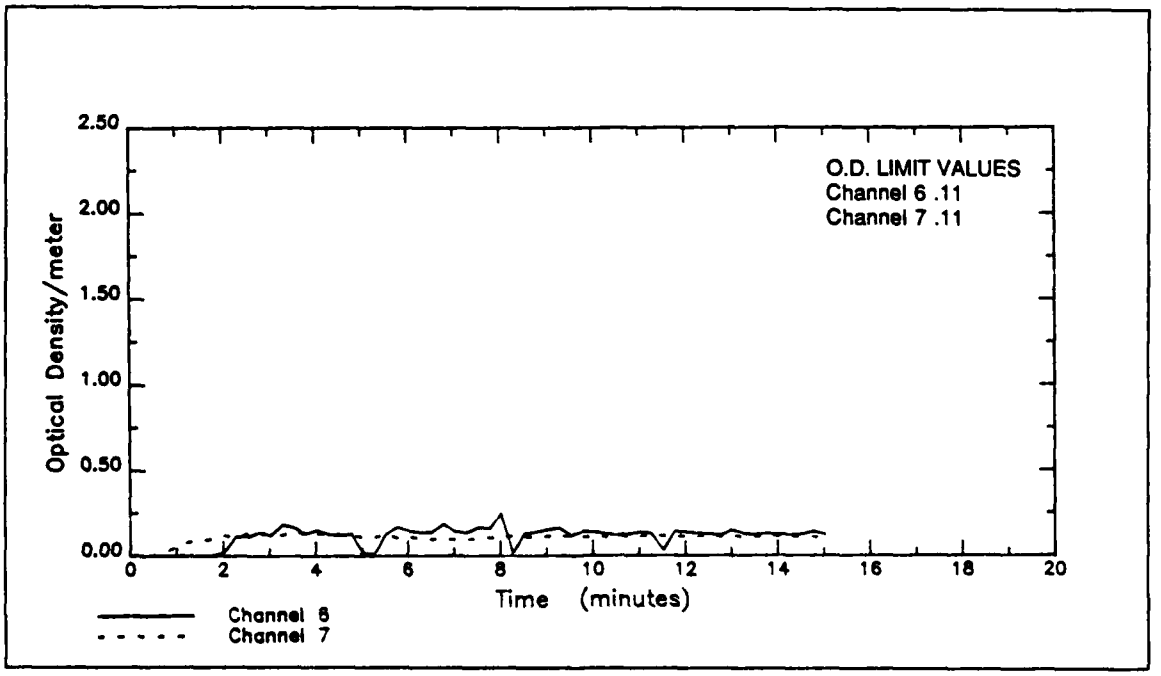



FIGURE B 9-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 9-2. OPTICAL DENSITY vs TIME**

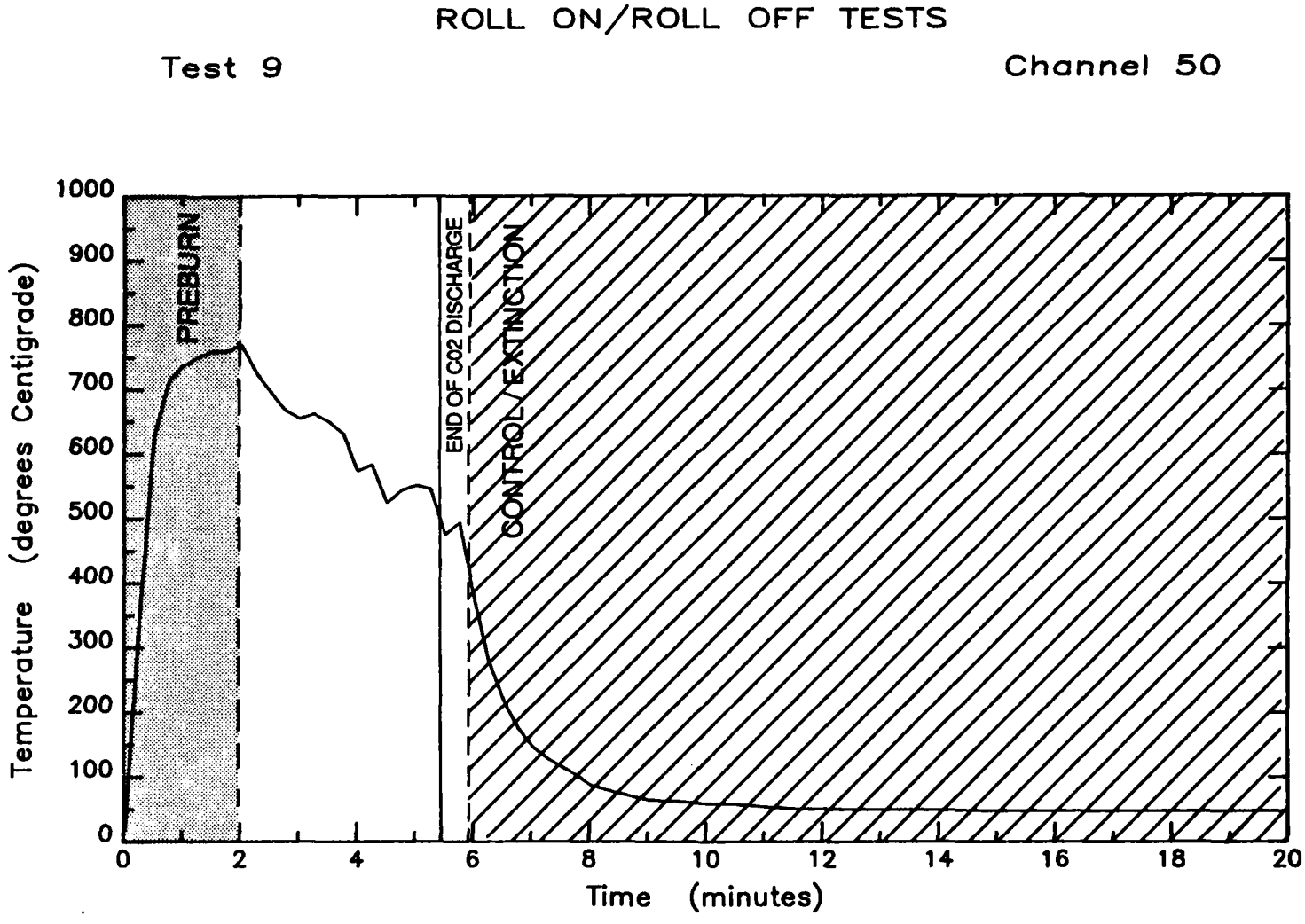
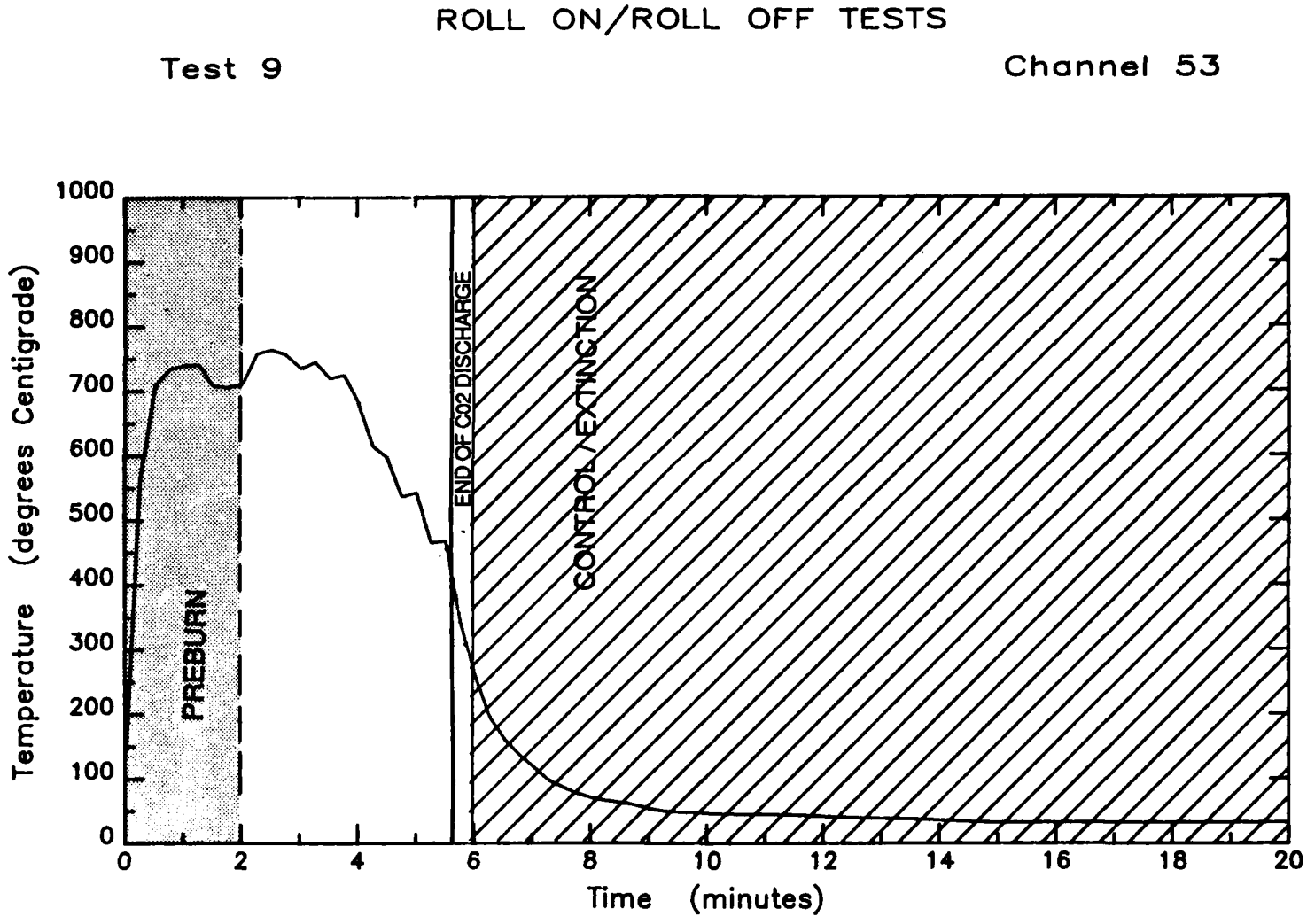



FIGURE B 9-3. Temperature vs Time - Location 9A




B 9-4

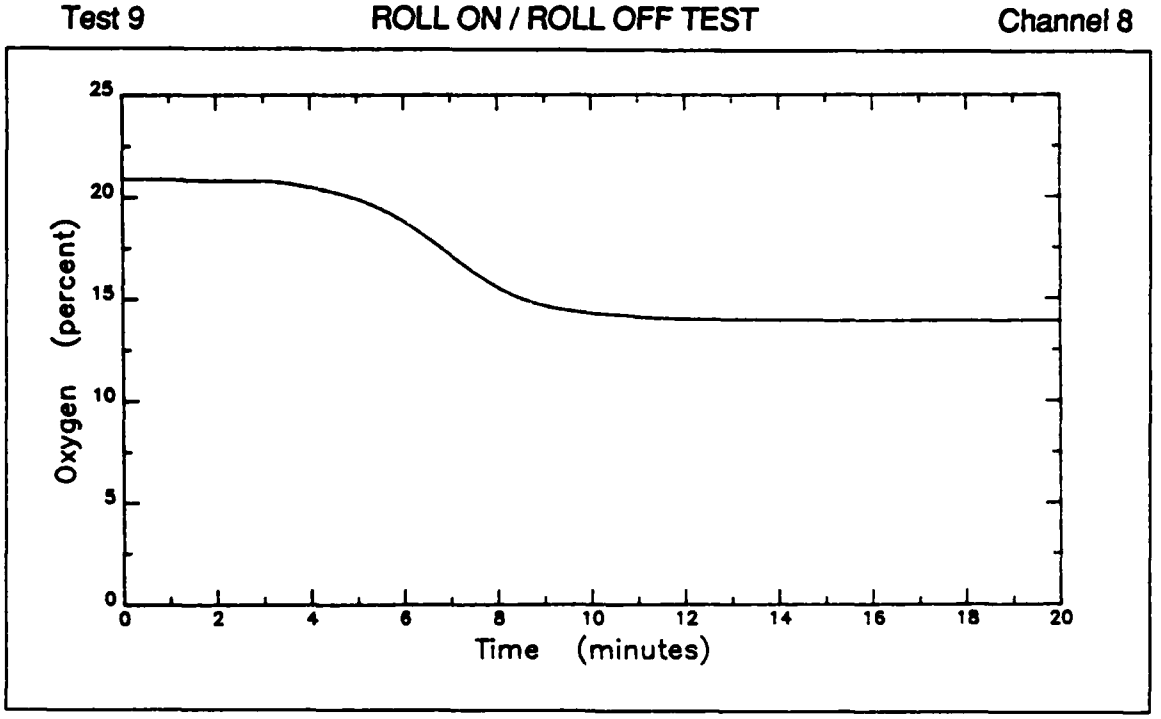
FIGURE B 9-4. Temperature vs Time - Location 10A

TEST 9

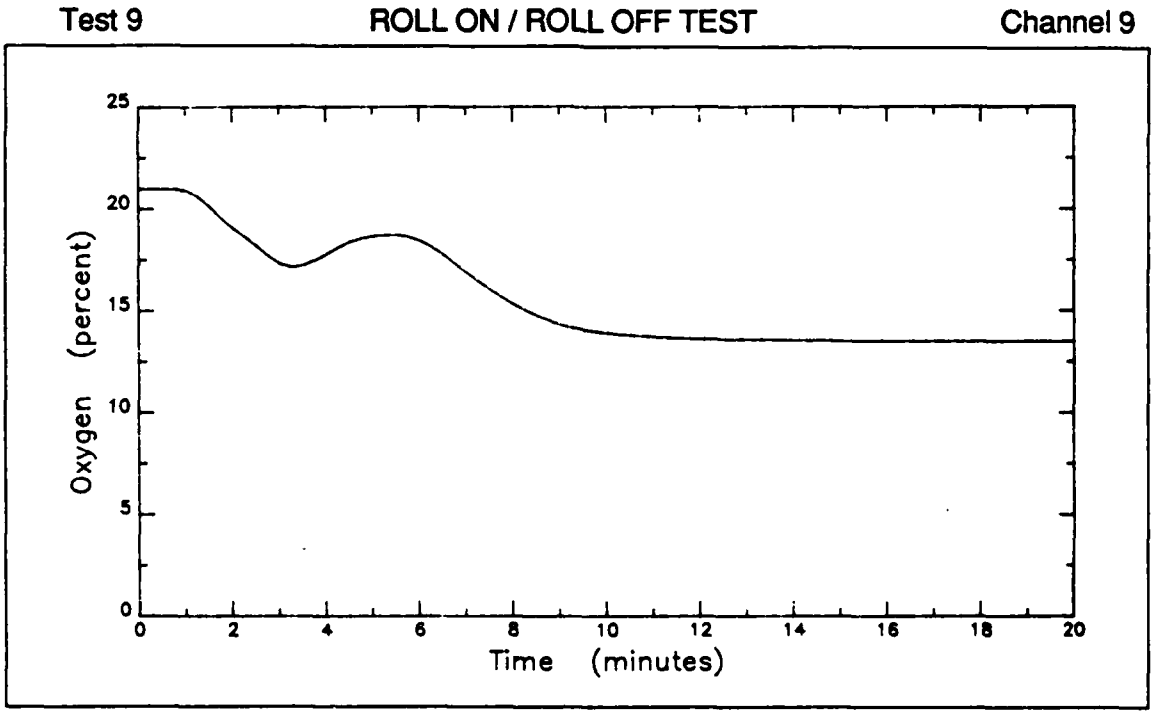
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 5.7 | 19.2 | 15.0 | 13.9 | 14.4% OXYGEN @ 9.5 MINUTES |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 5.7 | 19.6 | 14.5 | 13.7 | 14.4% OXYGEN @ 9.1 MINUTES |
| 11 | Auto 11A | 5.7 | 17.6 | 13.8 | 15.0 | |
| 12 | Auto 9B | 5.7 | 17.0 | 14.8 | 15.0 | |
| 13 | Auto 12B | 5.7 | 18.7 | 13.8 | 16.3 | |
| | | AVERAGE | 18.2 | 14.2 | 14.8 | |



FIGURE B 9-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

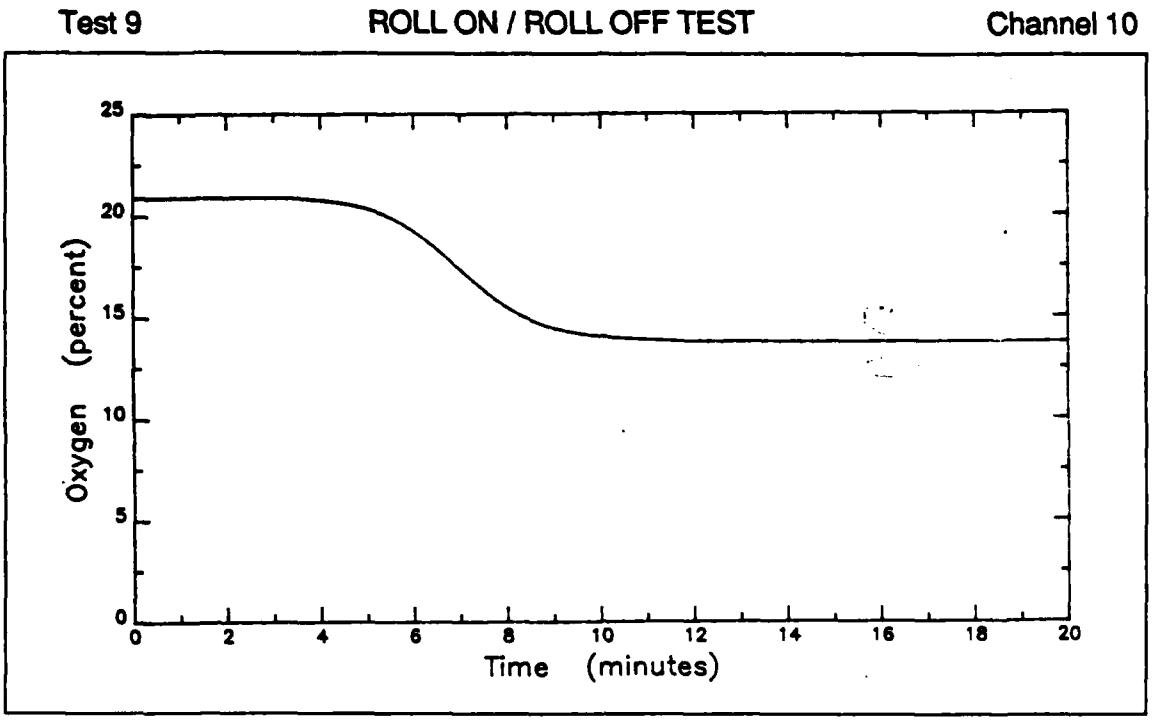



a. Test location - Automobile 9A

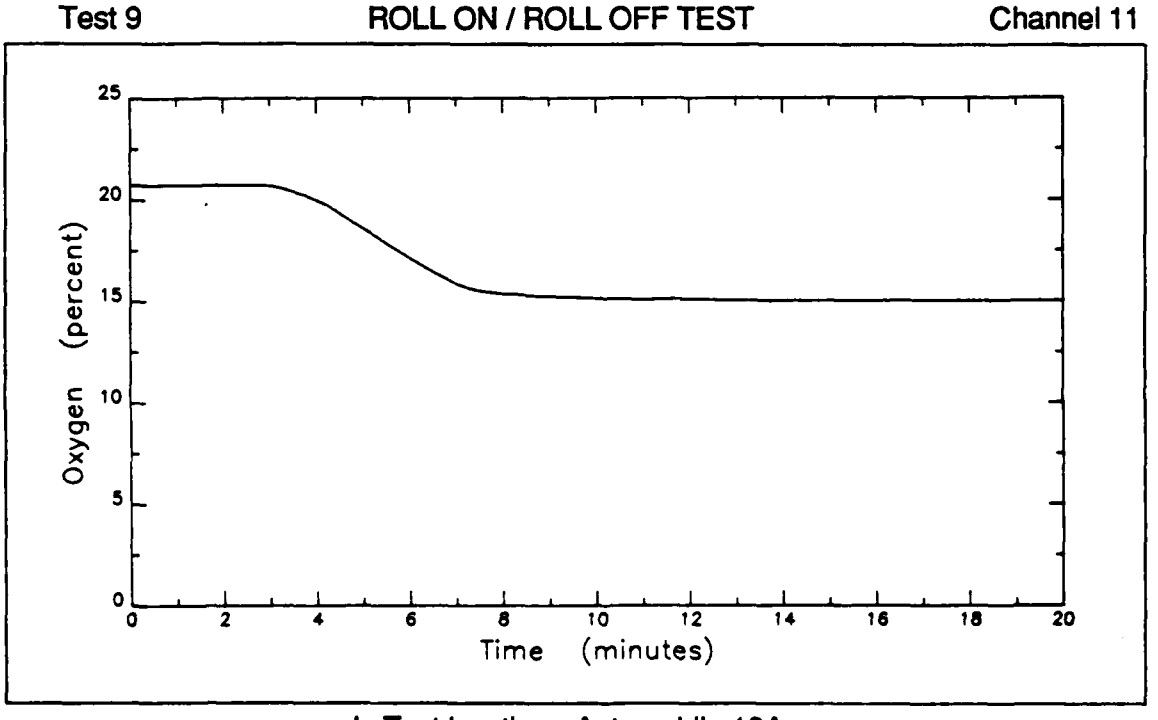



b. Test location - Automobile 10A

**FIGURE B 9-6. PERCENT OXYGEN vs TIME**

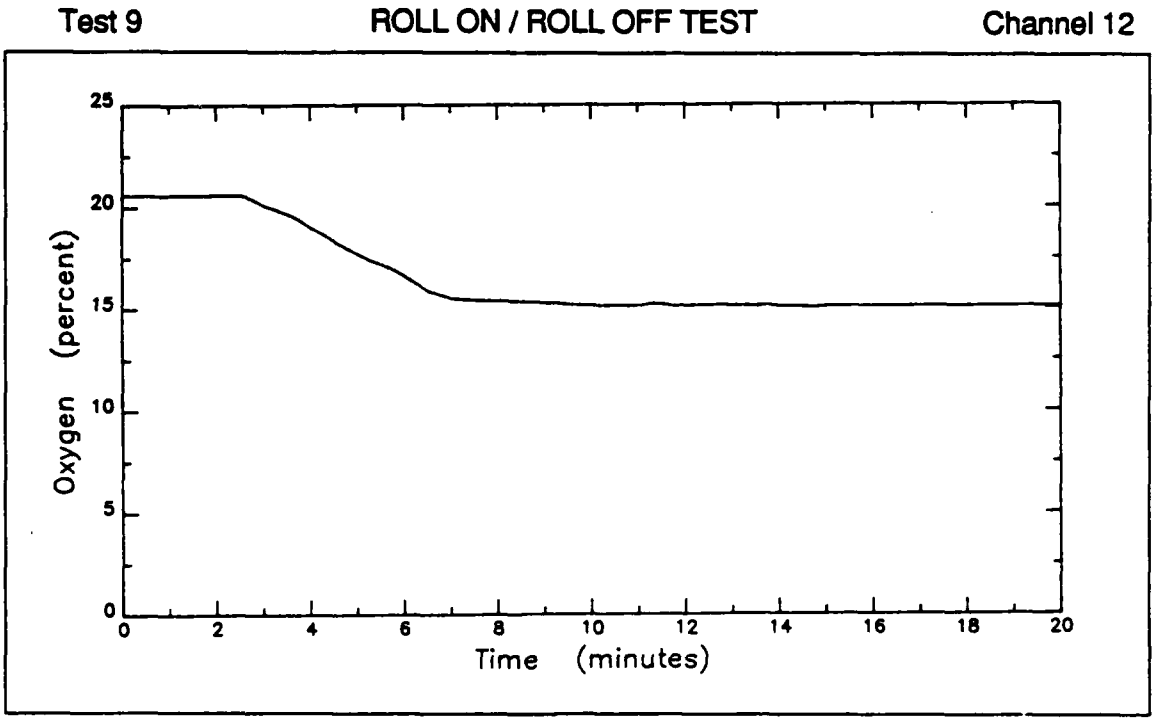



c. Test location - Automobile 11A

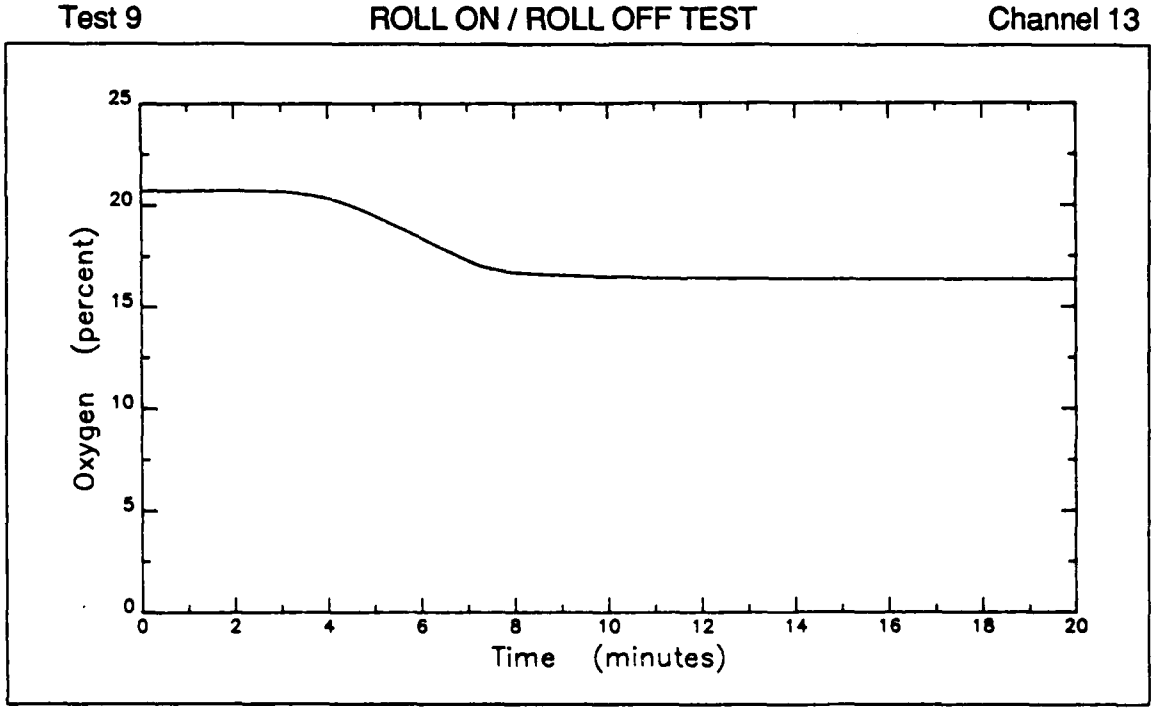



d. Test location - Automobile 12A

**FIGURE B 9-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B




f. Test location - Automobile 12B

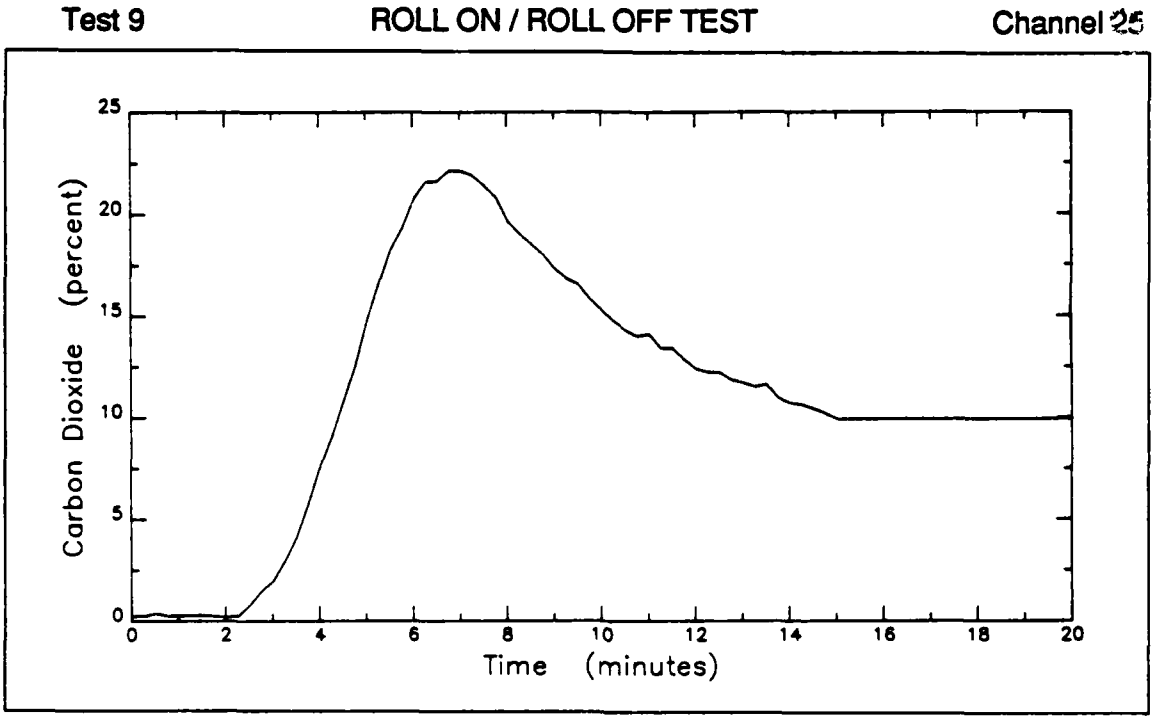
**FIGURE B 9-6. PERCENT OXYGEN vs TIME (cont'd)**

TEST 9

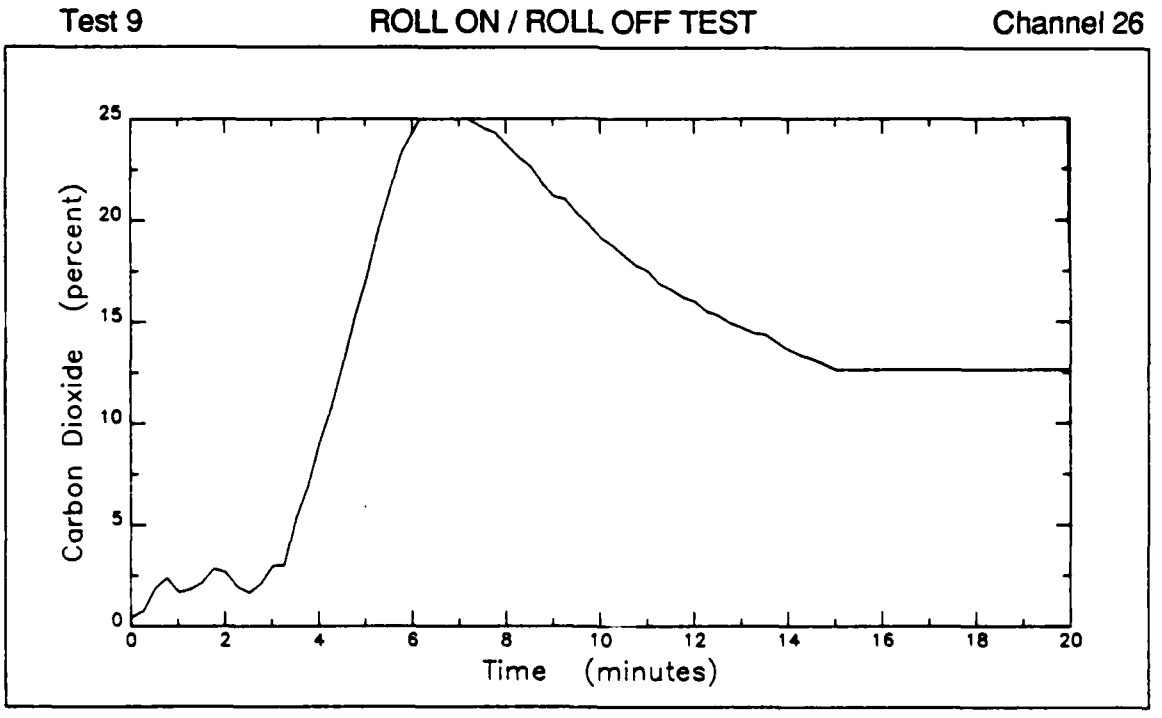
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 5.7 | 18.7 | 6.5 | 21.6 | |
| 26 | Auto 10A | 5.7 | 22.7 | 6.5 | 25.8 | |
| 27 | Auto 11A | 5.7 | 20.5 | 10.8 | 32.7 | |
| 28 | Auto 12A | 5.7 | 20.8 | 7.3 | 30.0 | |
| 29 | Auto 9C | 5.7 | 17.5 | 6.8 | 22.3 | |
| 30 | Auto 3A | 5.7 | 13.6 | 7.8 | 22.4 | |
| 31 | Auto 9B | 5.7 | 20.4 | 10.5 | 32.3 | |
| 32 | Auto 12B | 5.7 | 15.4 | 15.0 | 35.8 | |
| 33 | Auto 3B | 5.7 | 17.5 | 7.5 | 25.0 | |
| | | AVERAGE | 18.6 | 8.0 | 26.5 | |



FIGURE B 9-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

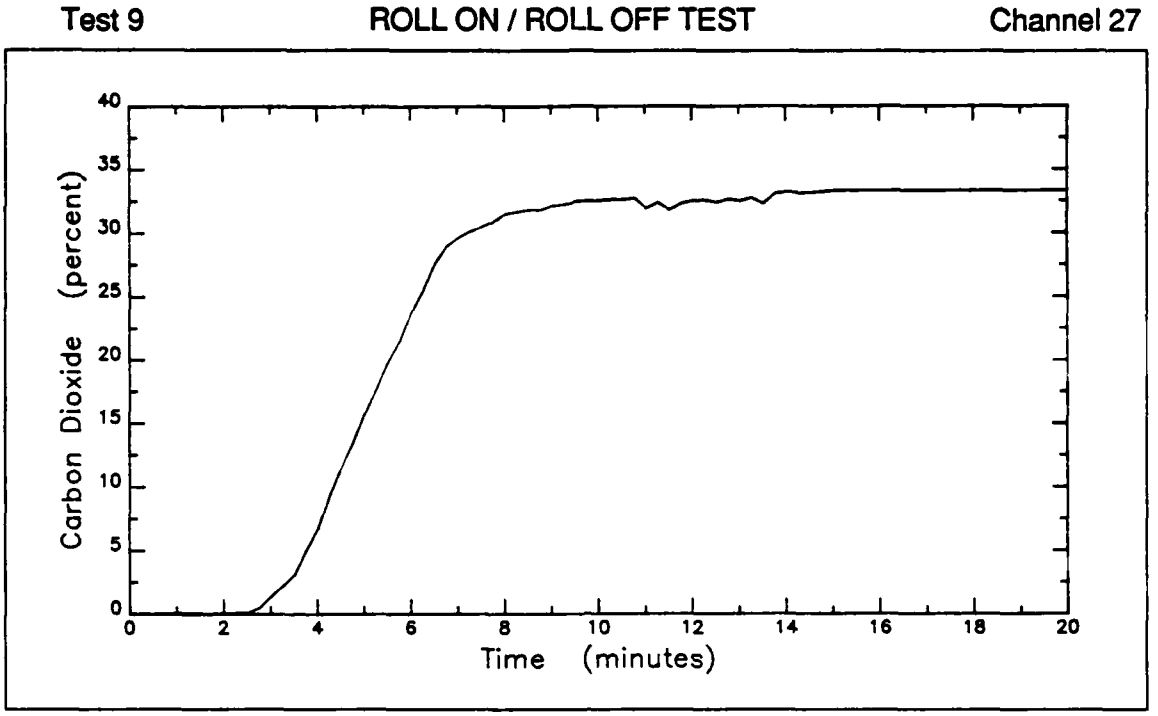



a. Test location - Automobile 9A

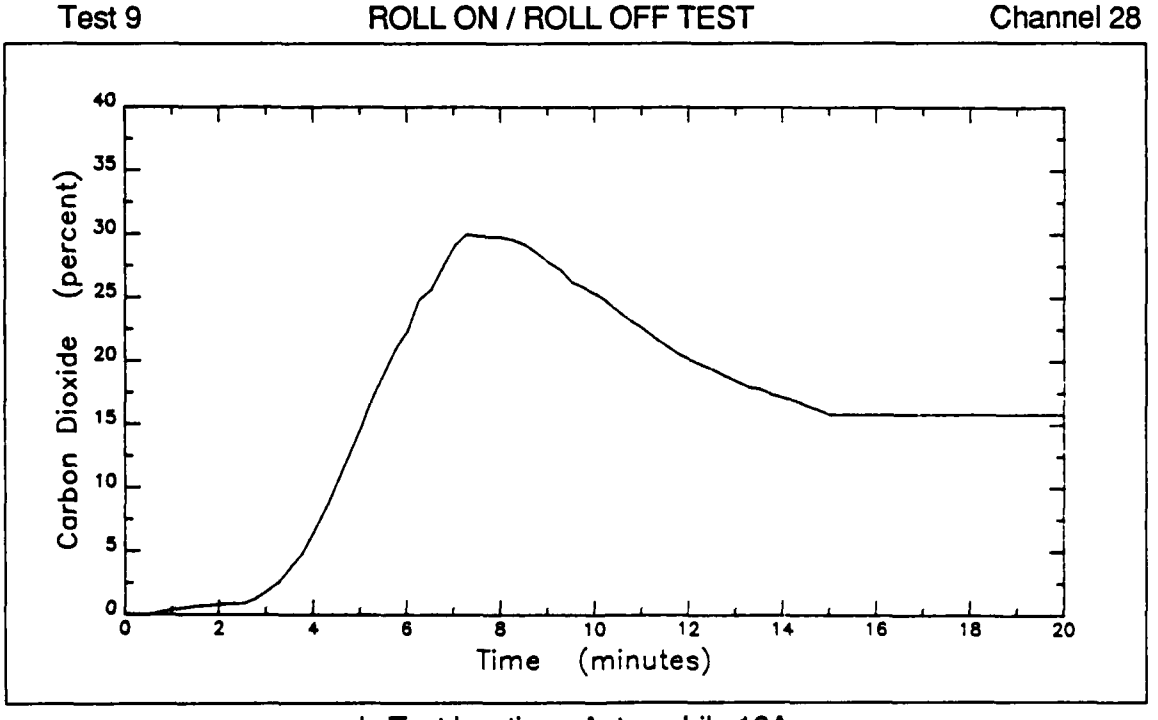



b. Test location - Automobile 10A

**FIGURE B 9-8. PERCENT CARBON DIOXIDE vs TIME**

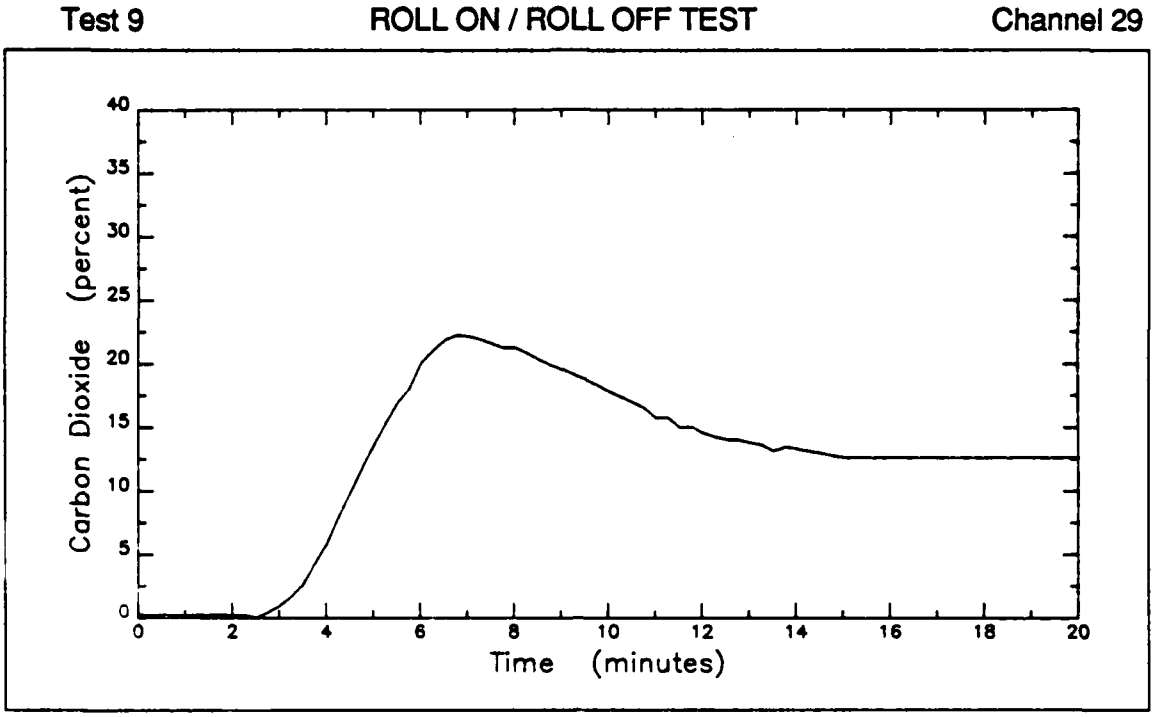



c. Test location - Automobile 11A

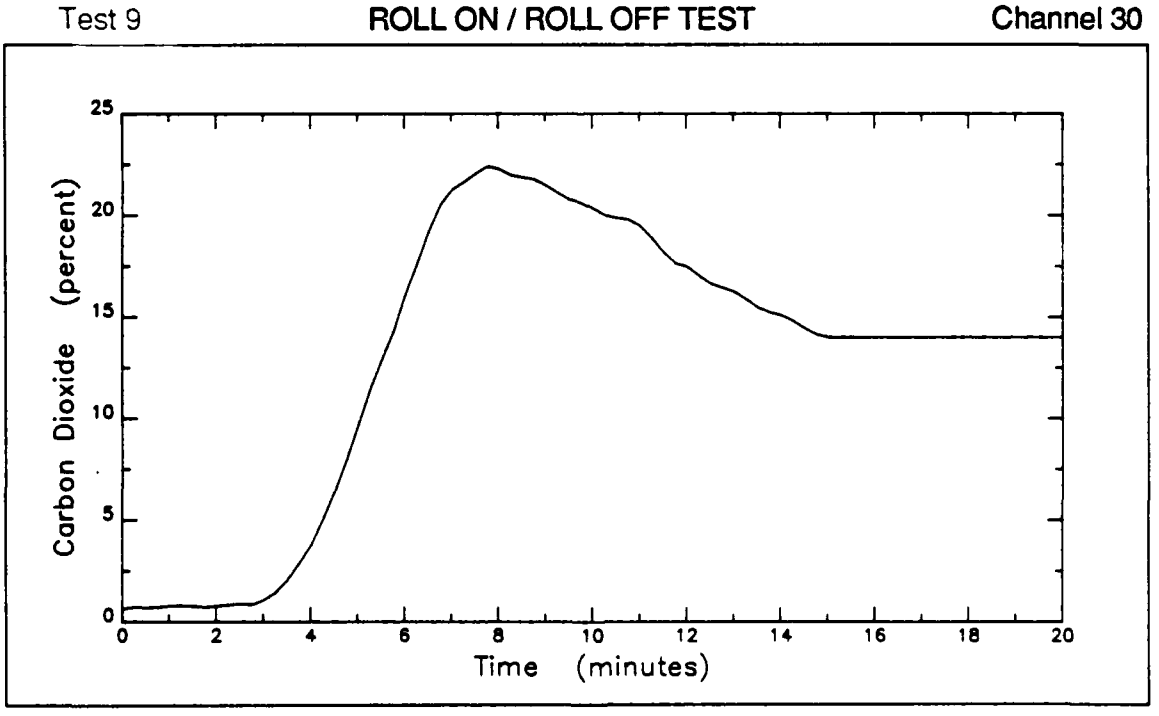



d. Test location - Automobile 12A

**FIGURE B 9-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

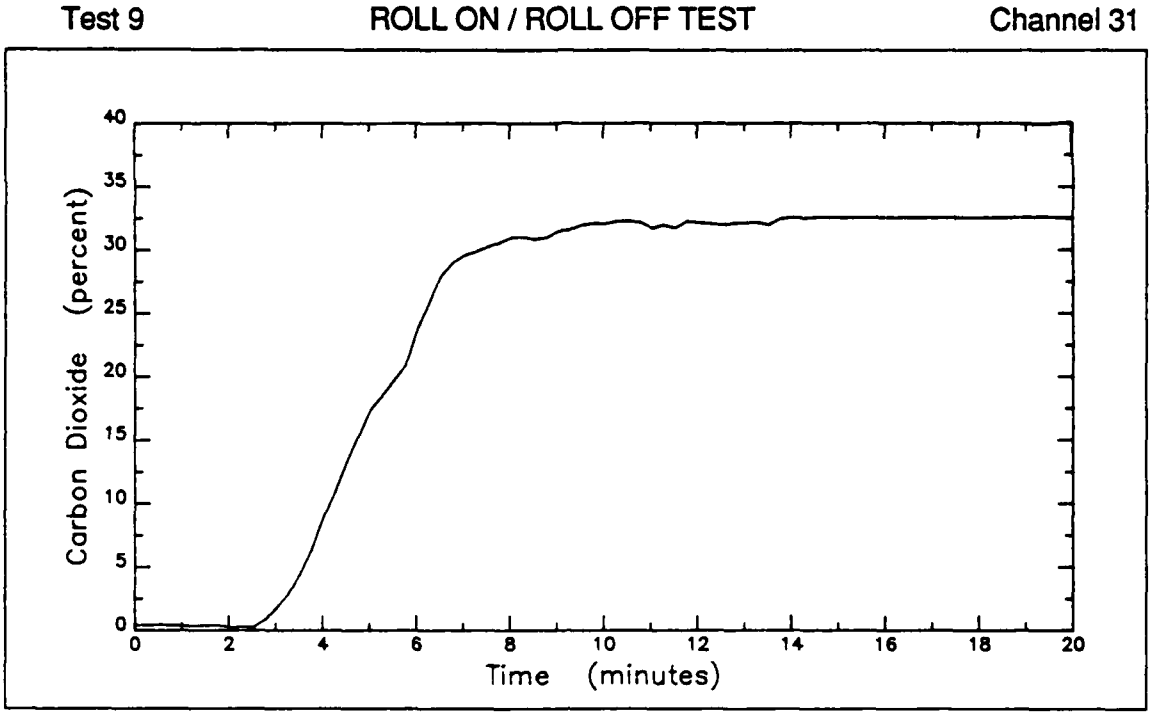



e. Test location - Automobile 9C

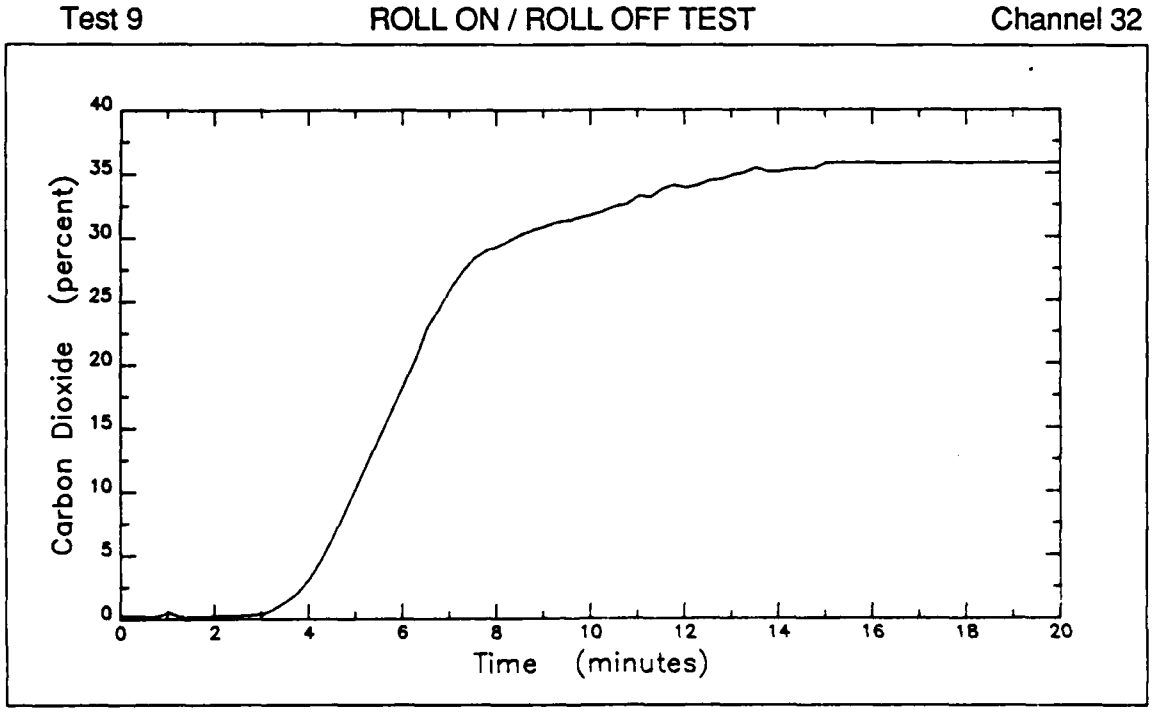



f. Test location - Automobile 3A

**FIGURE B 9-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

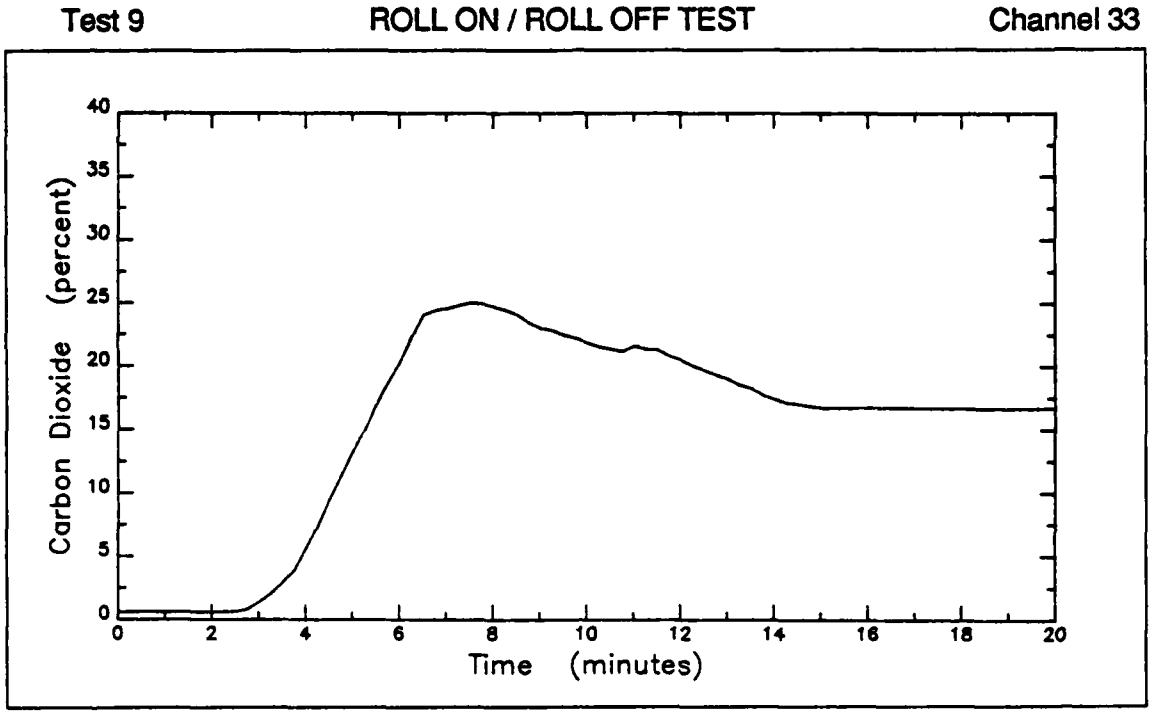



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 9-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

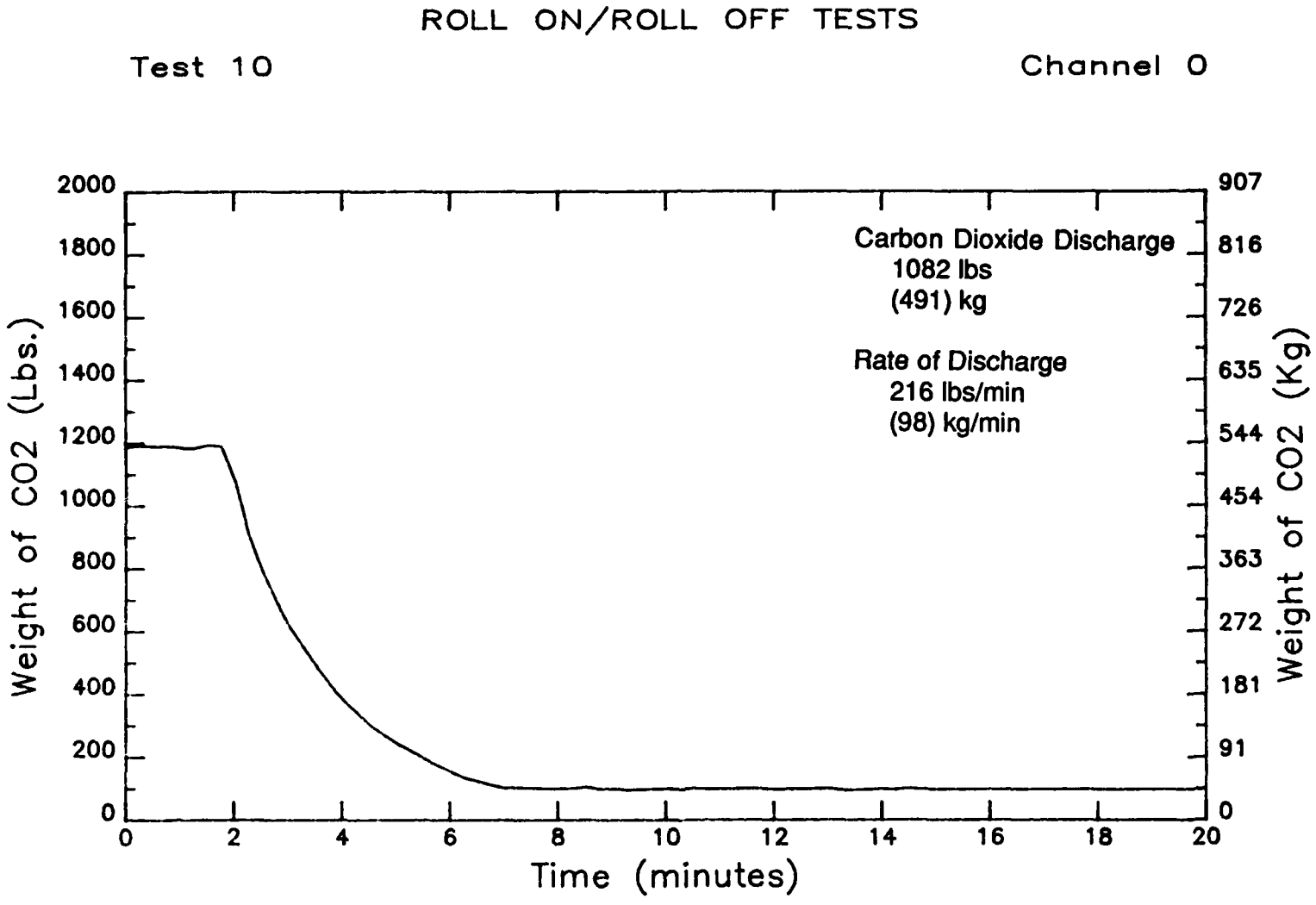



i. Test location - Automobile 3B

**FIGURE B 9-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

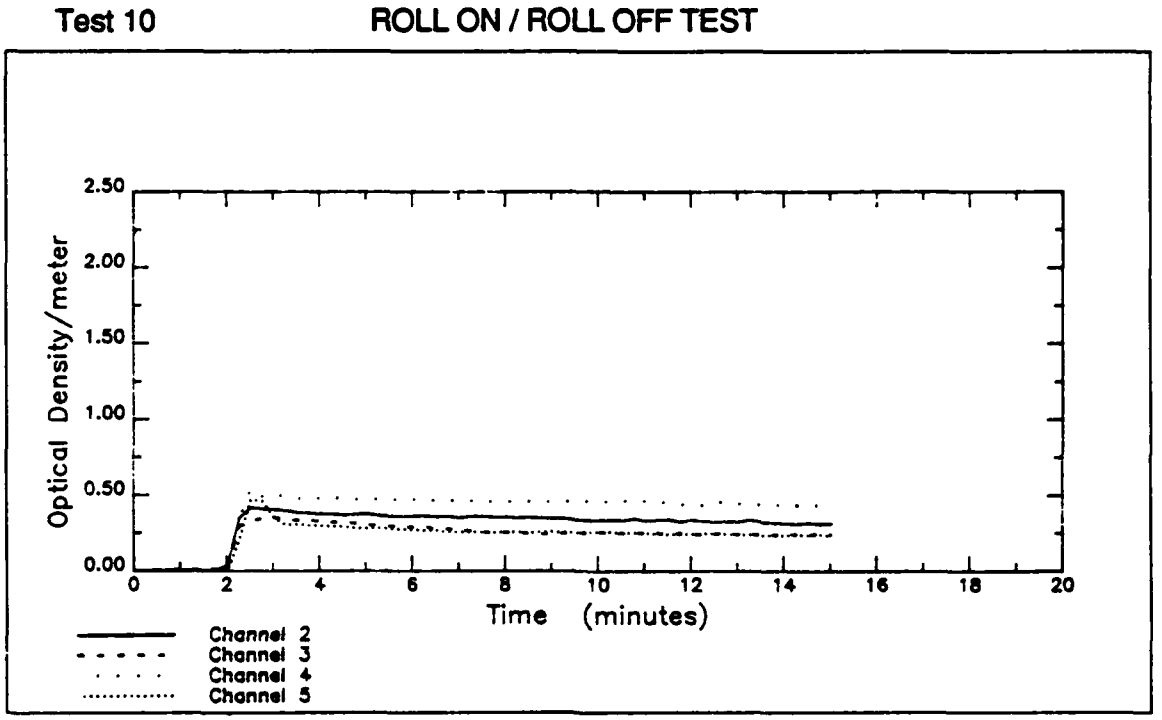
# APPENDIX B

# TEST 10

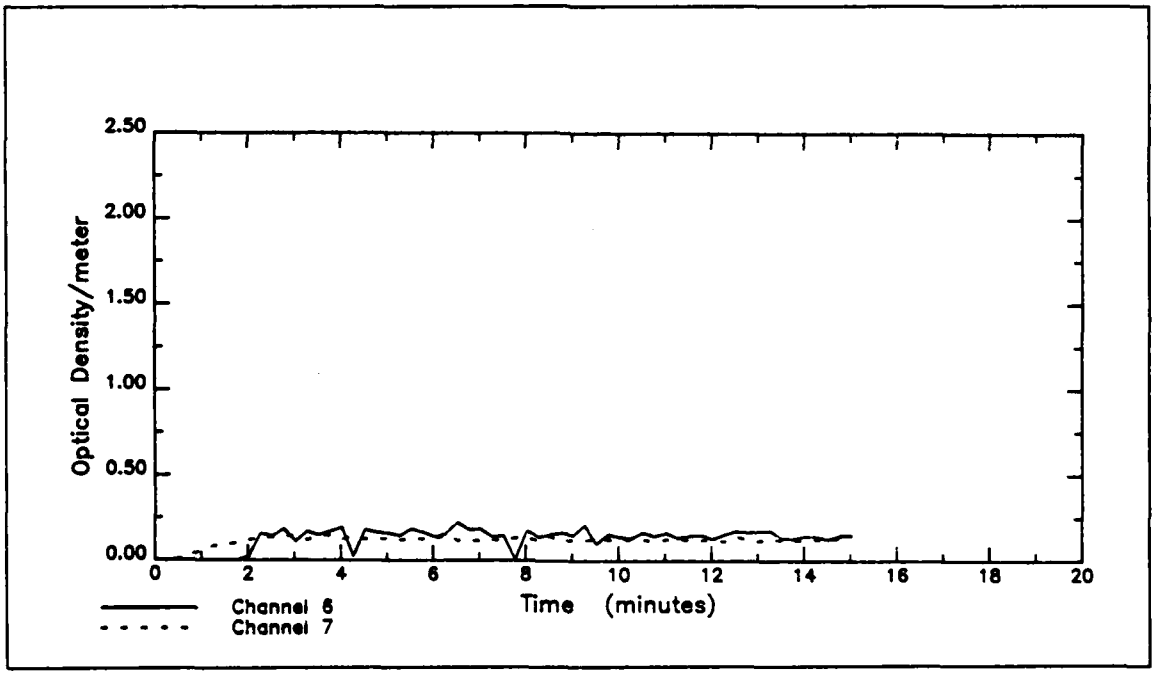



B 10-1

FIGURE B 10-1. Weight of Carbon Dioxide vs Time

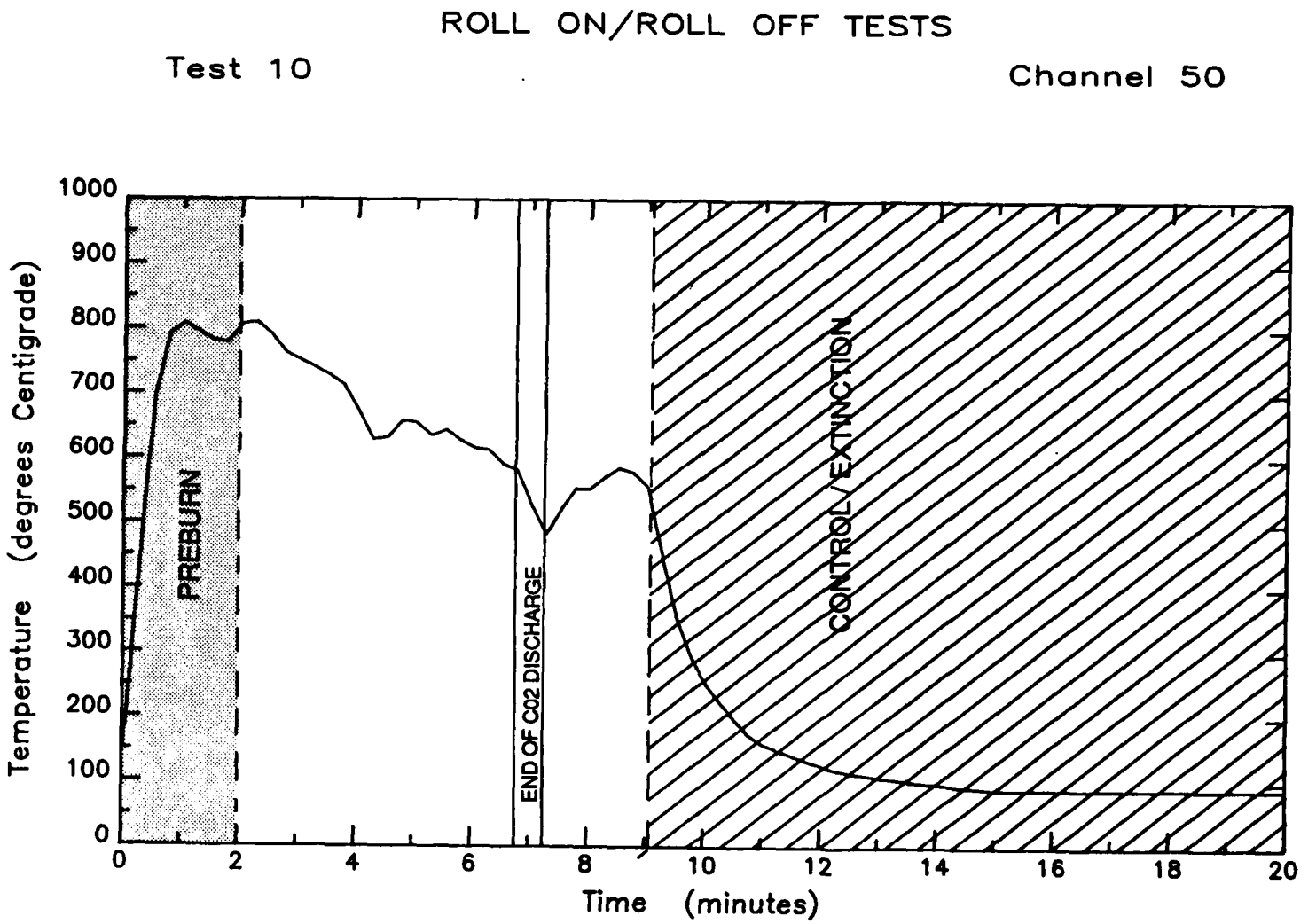



a. Data Channels 2,3,4,5



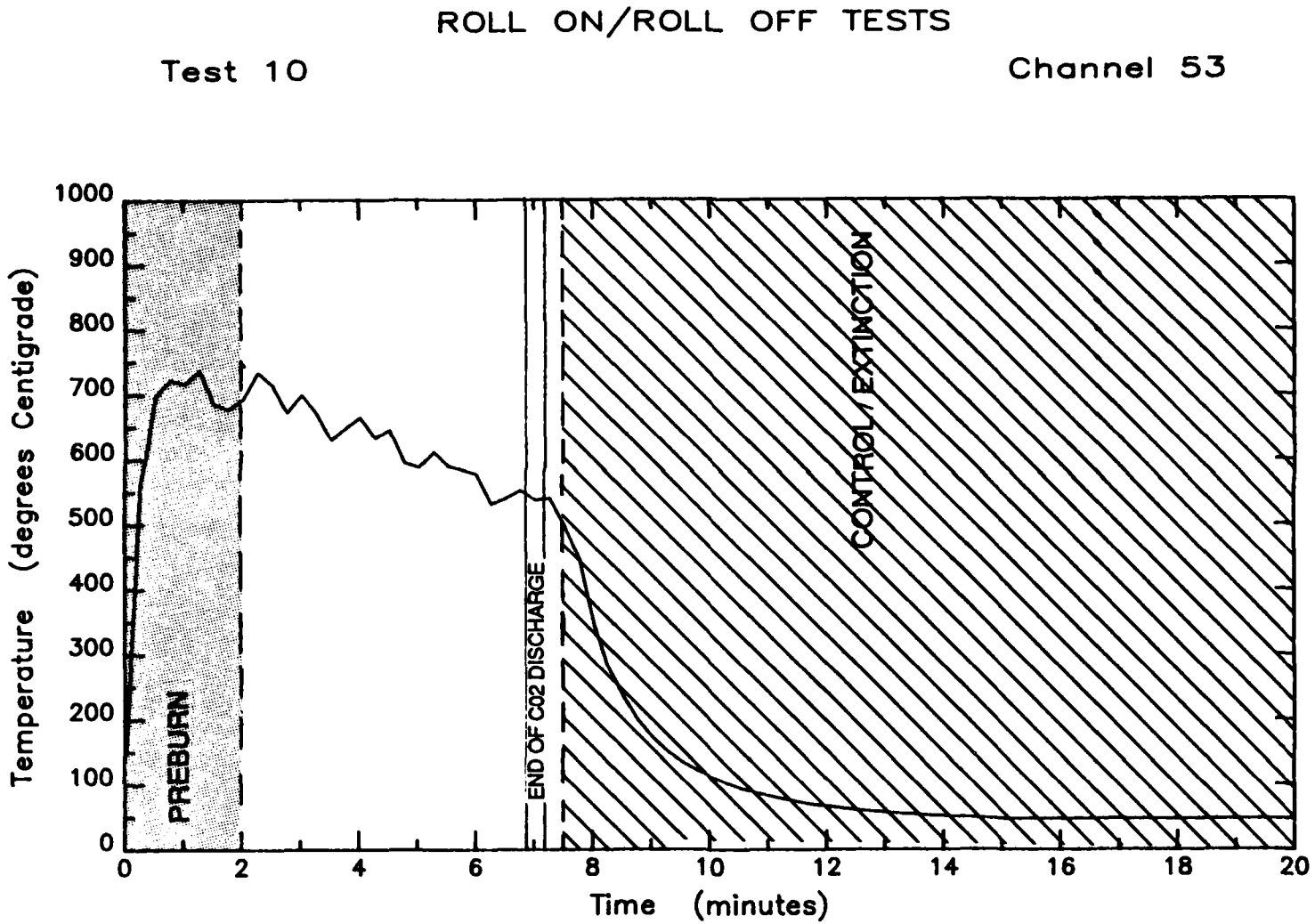

b. Data Channels 6, 7

**FIGURE 10-2. OPTICAL DENSITY vs TIME**




B 10-3

FIGURE B 10-3. Temperature vs Time - Location 9A




B 10-4

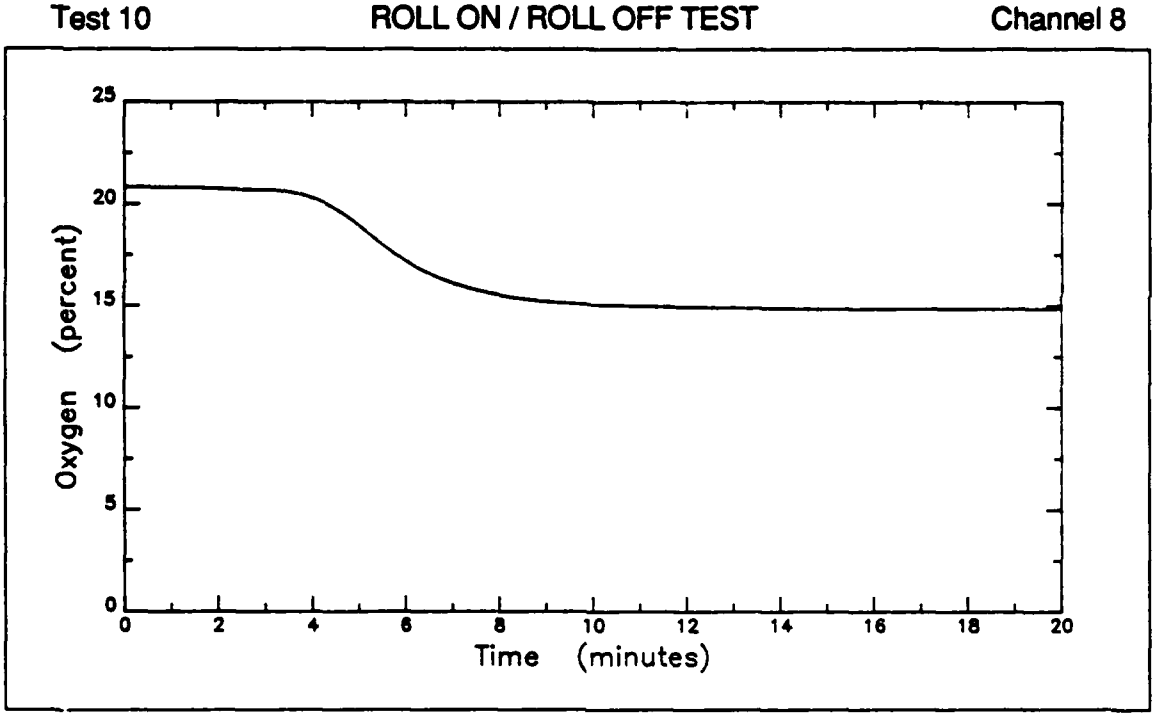
FIGURE B 10-4. Temperature vs Time - Location 10A

TEST 10

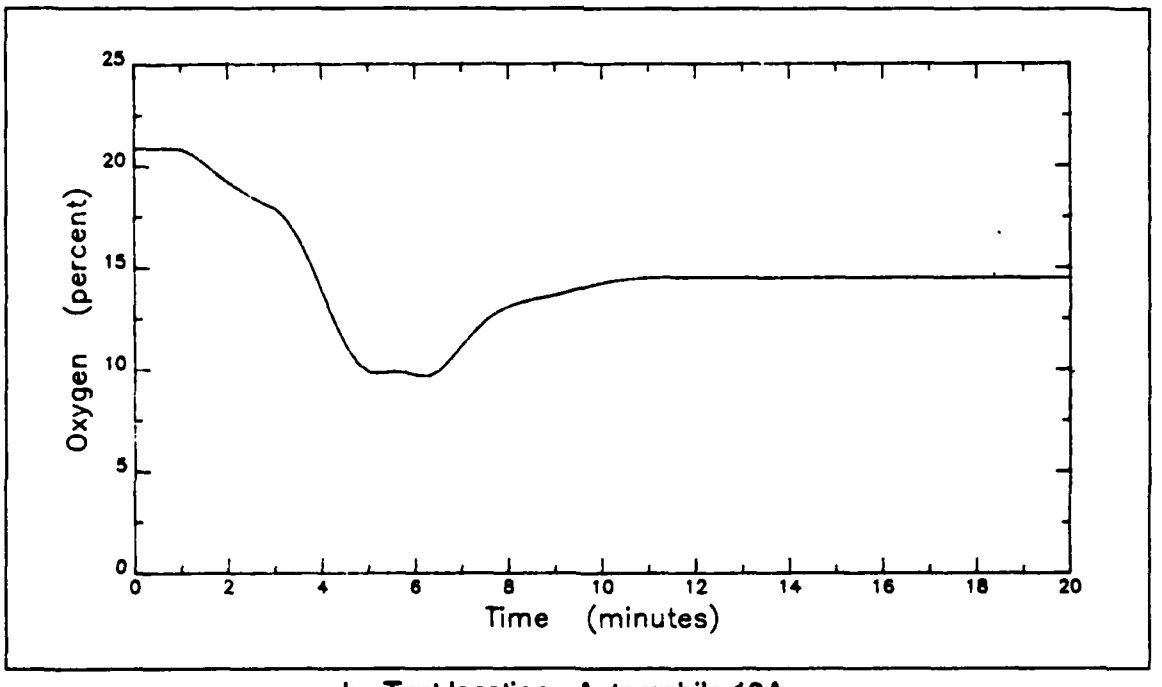
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 7.6 | 15.7 | 15.0 | 14.8 | |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 7.6 | 16.0 | 12.8 | 14.7 | |
| 11 | Auto 11A | 7.6 | 16.2 | 11.8 | 15.9 | |
| 12 | Auto 9B | 7.6 | 16.0 | 11.0 | 15.7 | |
| 13 | Auto 12B | 7.6 | 17.2 | 11.6 | 17.0 | |
| | | AVERAGE | 16.2 | 11.8 | 15.8 | |



FIGURE B 10-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

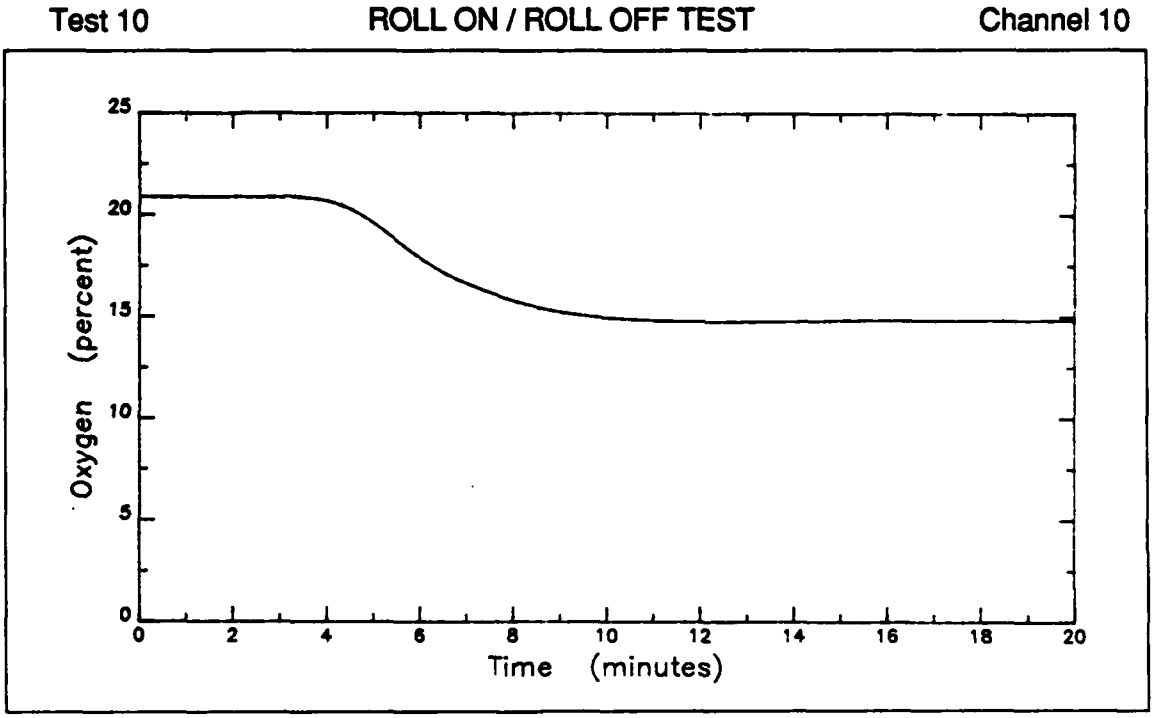



a. Test location - Automobile 9A

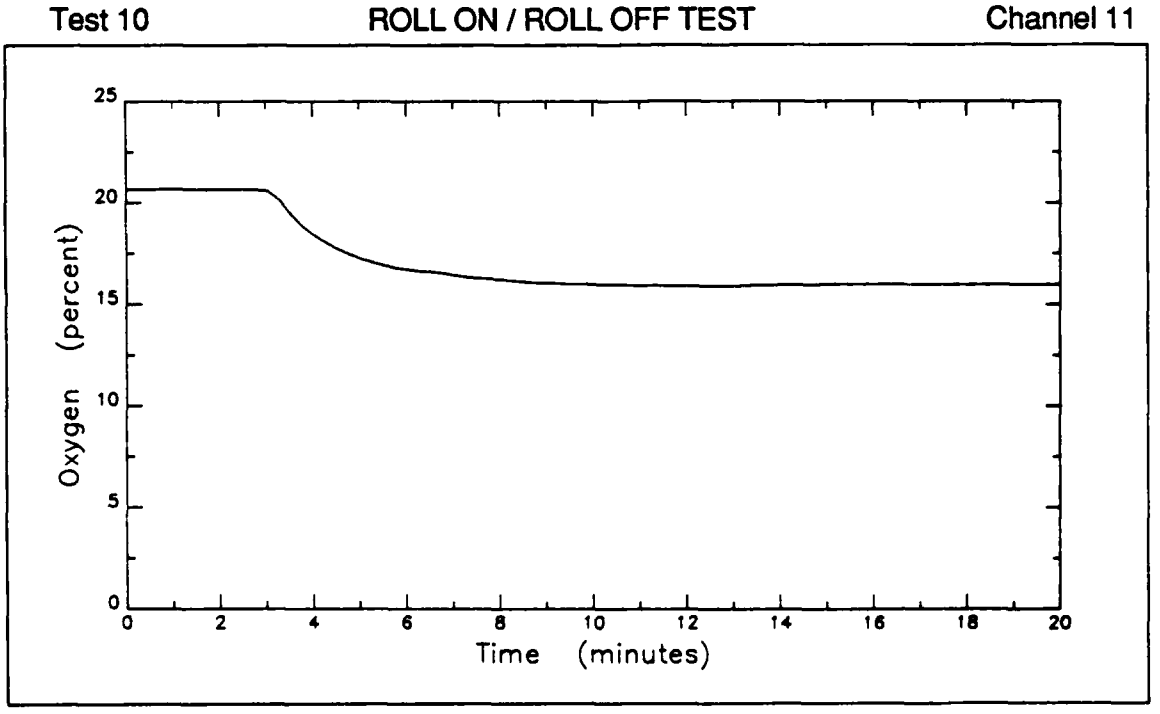



b. Test location - Automobile 10A

**FIGURE B 10-6. PERCENT OXYGEN vs TIME**

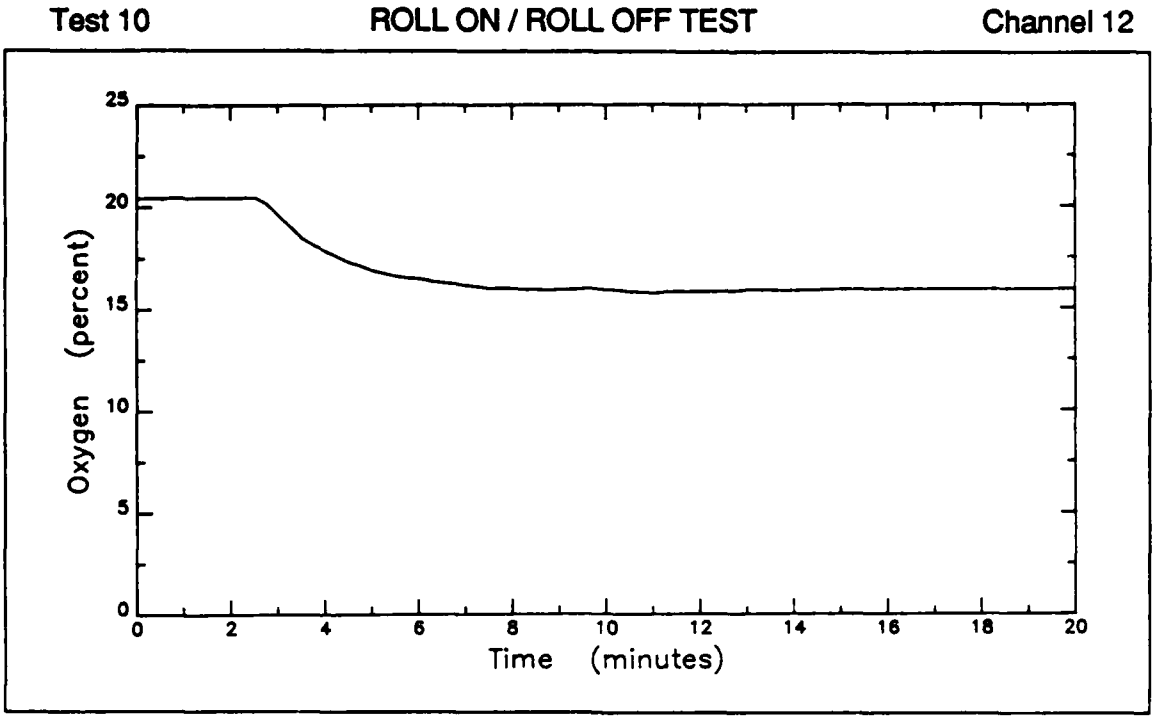



c. Test location - Automobile 11A

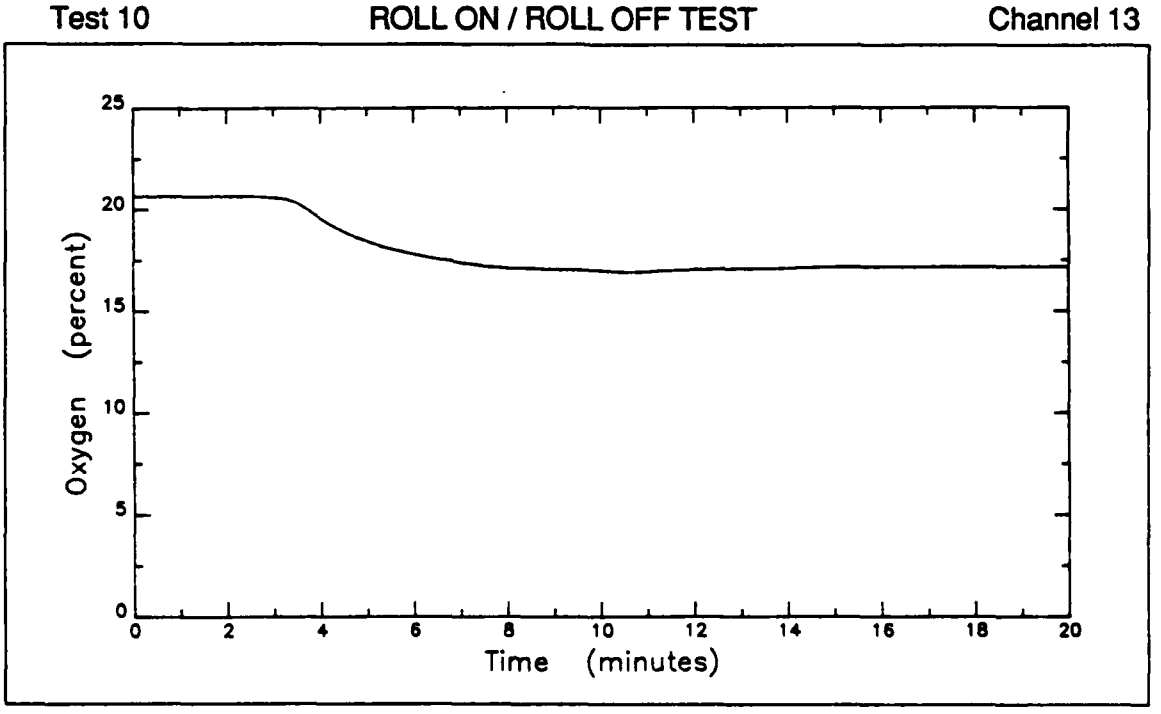



d. Test location - Automobile 12A

**FIGURE B 10-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B




f. Test location - Automobile 12B

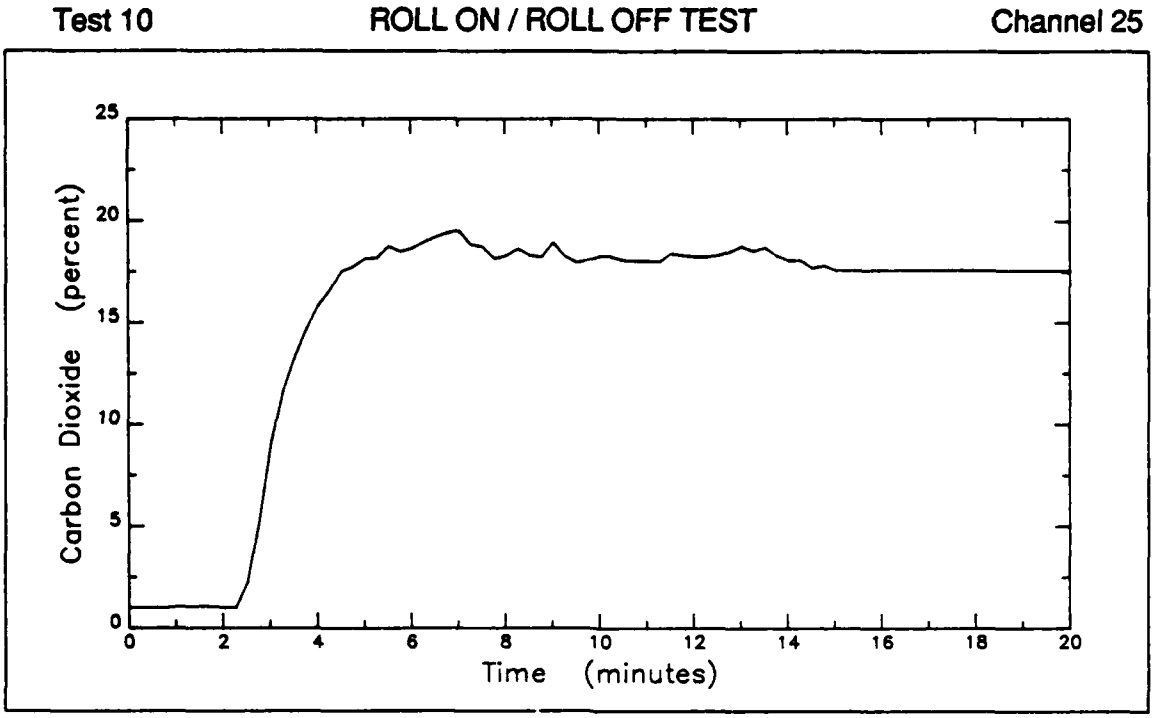
**FIGURE B 10-6. PERCENT OXYGEN vs TIME (cont'd)**

TEST 10

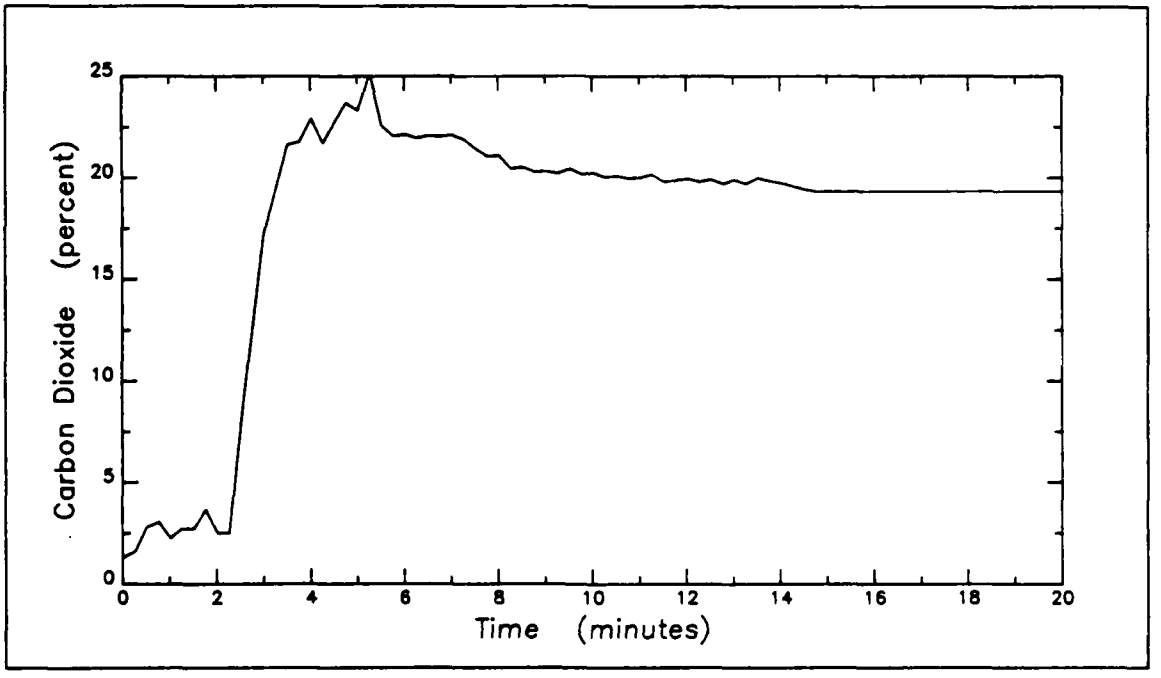
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 7.6 | 18.4 | 7.0 | 19.5 | |
| 26 | Auto 10A | 7.6 | 21.2 | 4.8 | 23.7 | |
| 27 | Auto 11A | 7.6 | 25.7 | 11.0 | 26.8 | |
| 28 | Auto 12A | 7.6 | 28.3 | 7.5 | 28.5 | |
| 29 | Auto 9C | 7.6 | 18.7 | 7.5 | 18.8 | |
| 30 | Auto 3A | 7.6 | 20.3 | 6.8 | 20.9 | |
| 31 | Auto 9B | 7.6 | 28.7 | 10.0 | 29.0 | |
| 32 | Auto 12B | 7.6 | 26.3 | 15.0 | 28.9 | |
| 33 | Auto 3B | 7.6 | 22.0 | 6.5 | 22.6 | |
| | | AVERAGE | 23.3 | 7.6 | 23.7 | |



FIGURE B 10-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

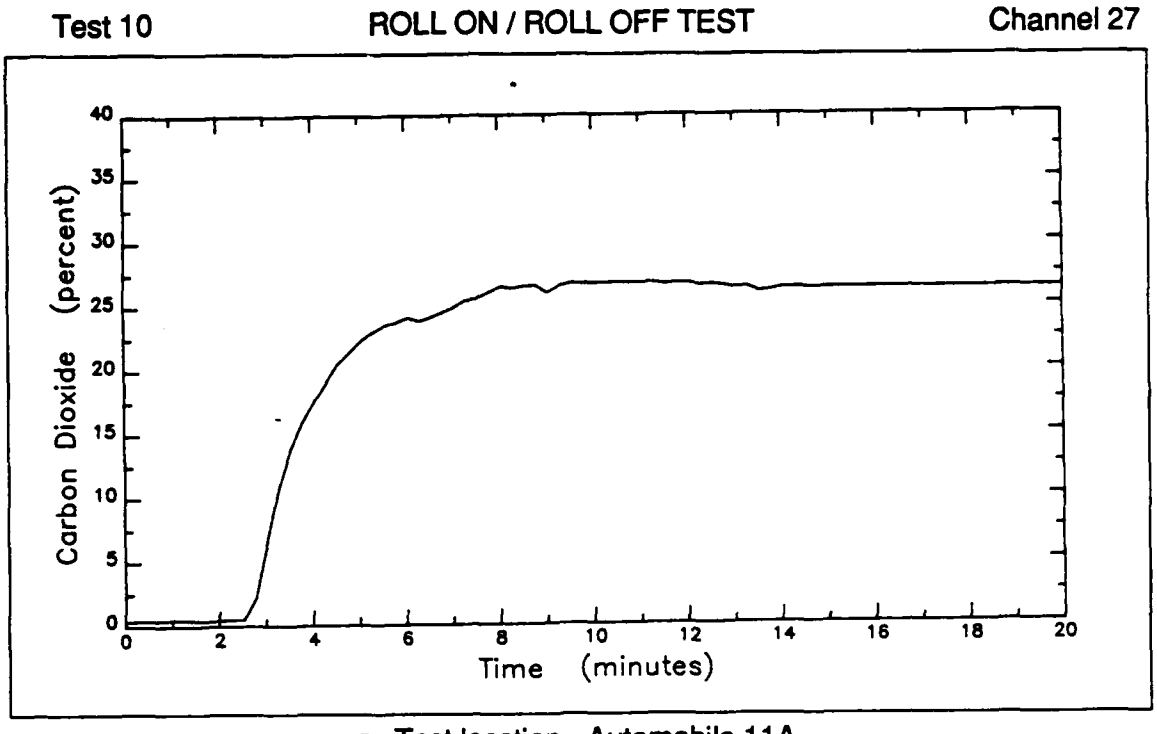



a. Test location - Automobile 9A

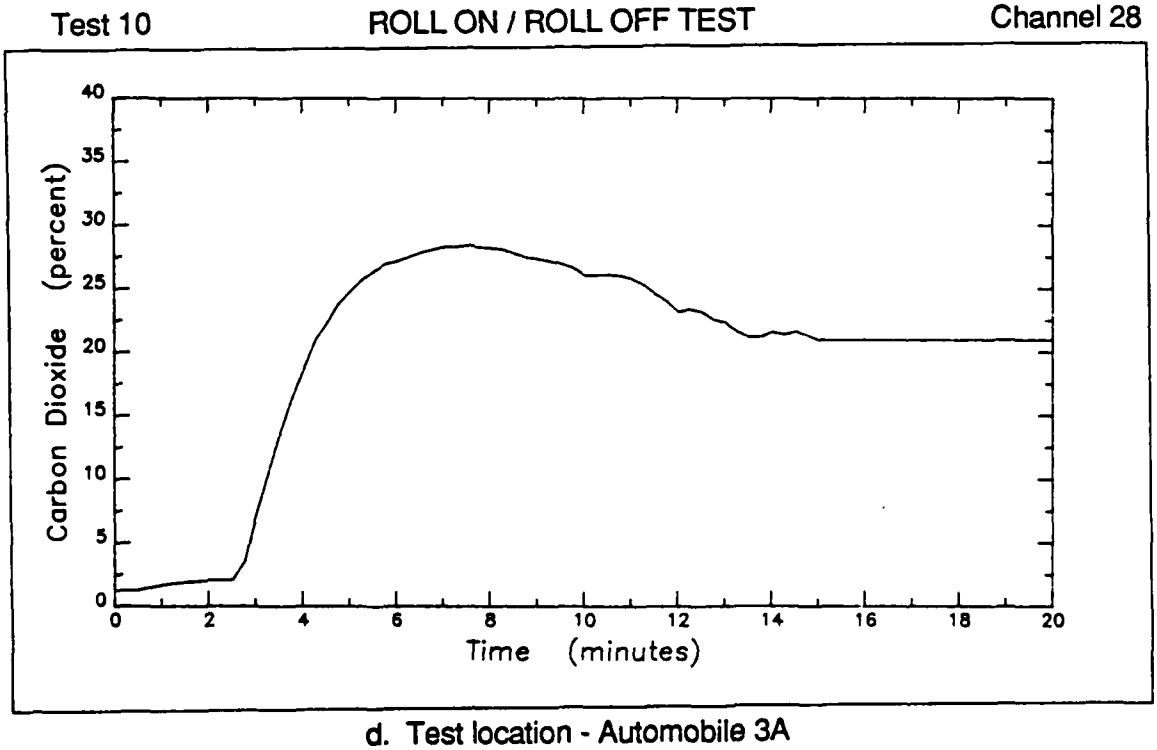



b. Test location - Automobile 10A

**FIGURE B 10-8. PERCENT CARBON DIOXIDE vs TIME**

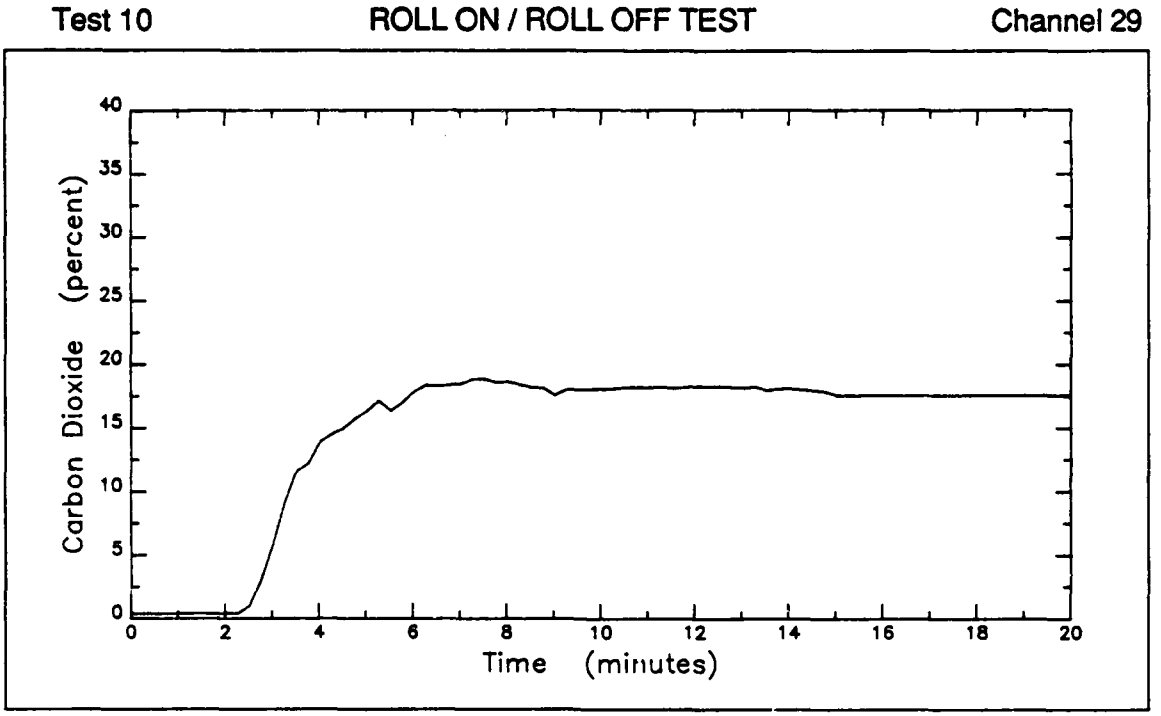



c. Test location - Automobile 11A

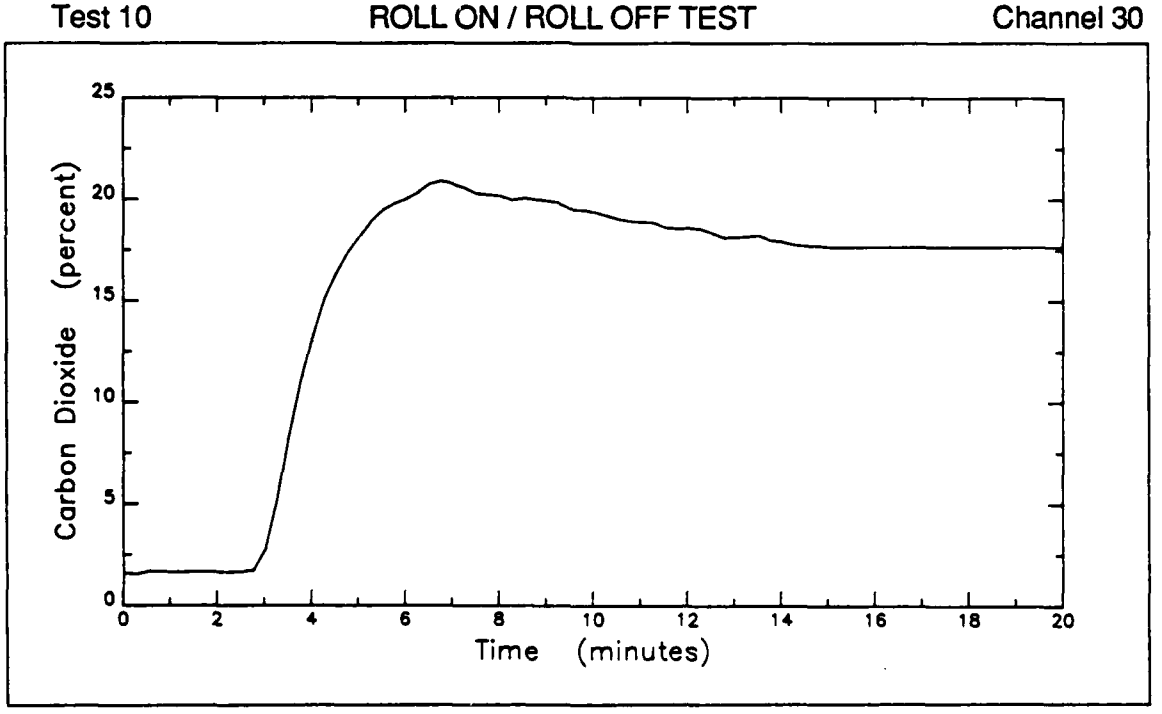



d. Test location - Automobile 3A

**FIGURE B 10-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

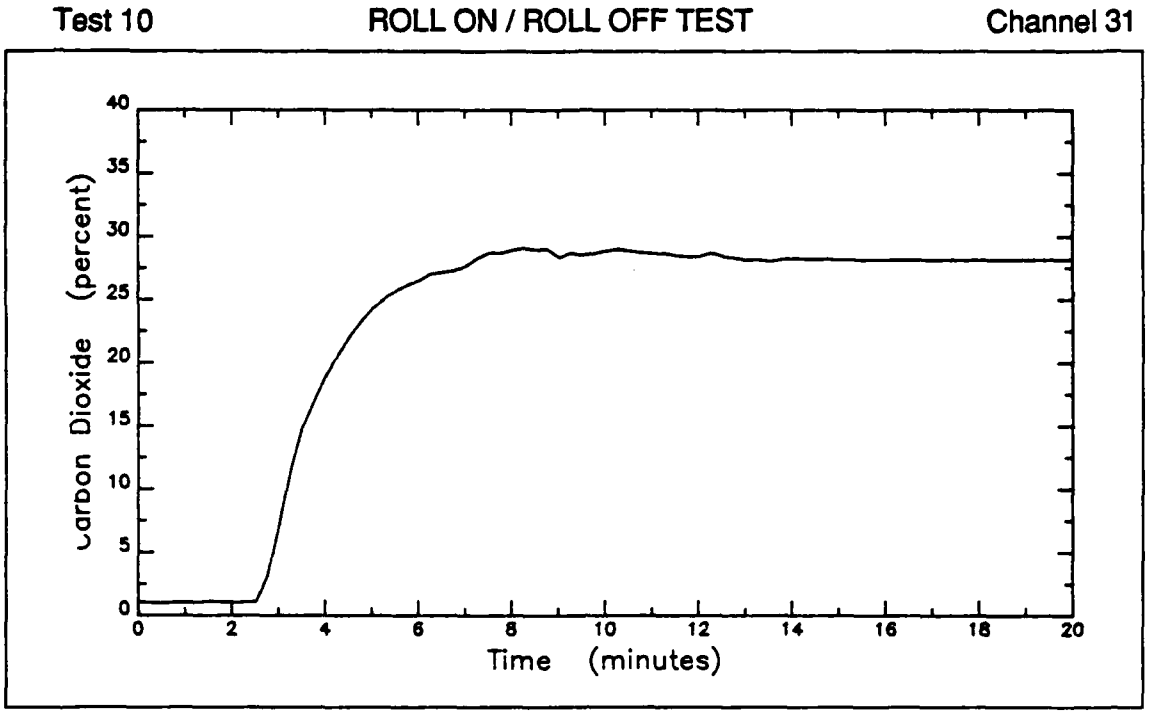



e. Test location - Automobile 9c

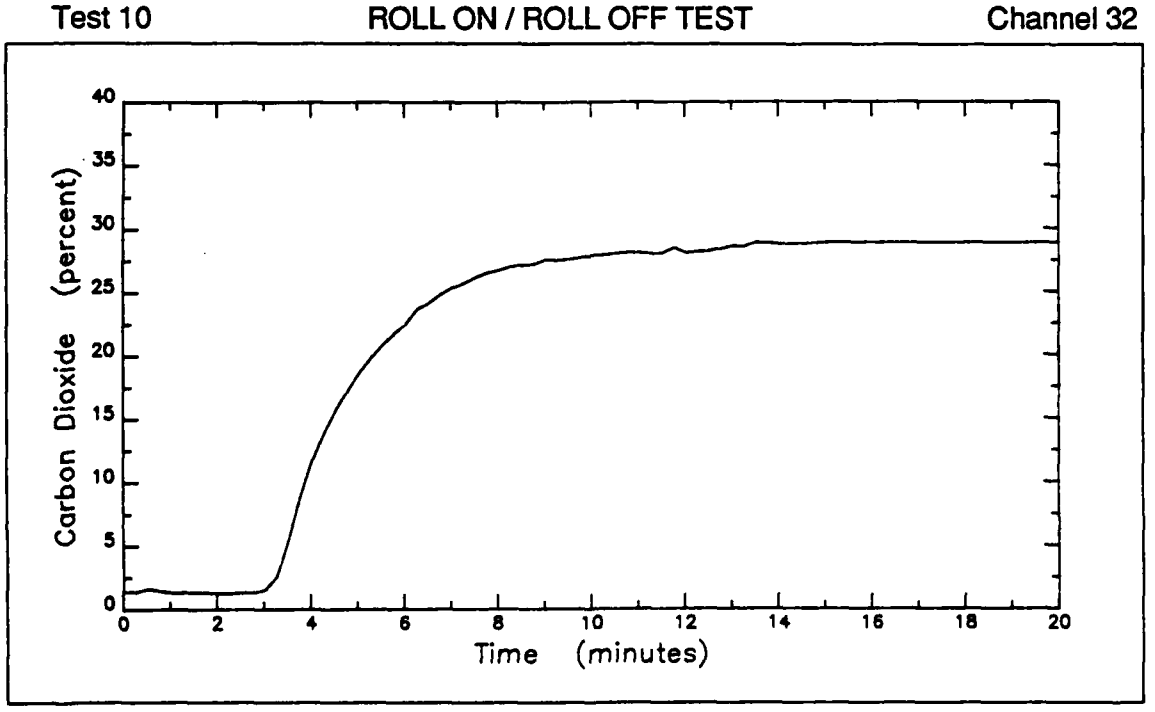



f. Test location - Automobile 3A

**FIGURE B 10-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

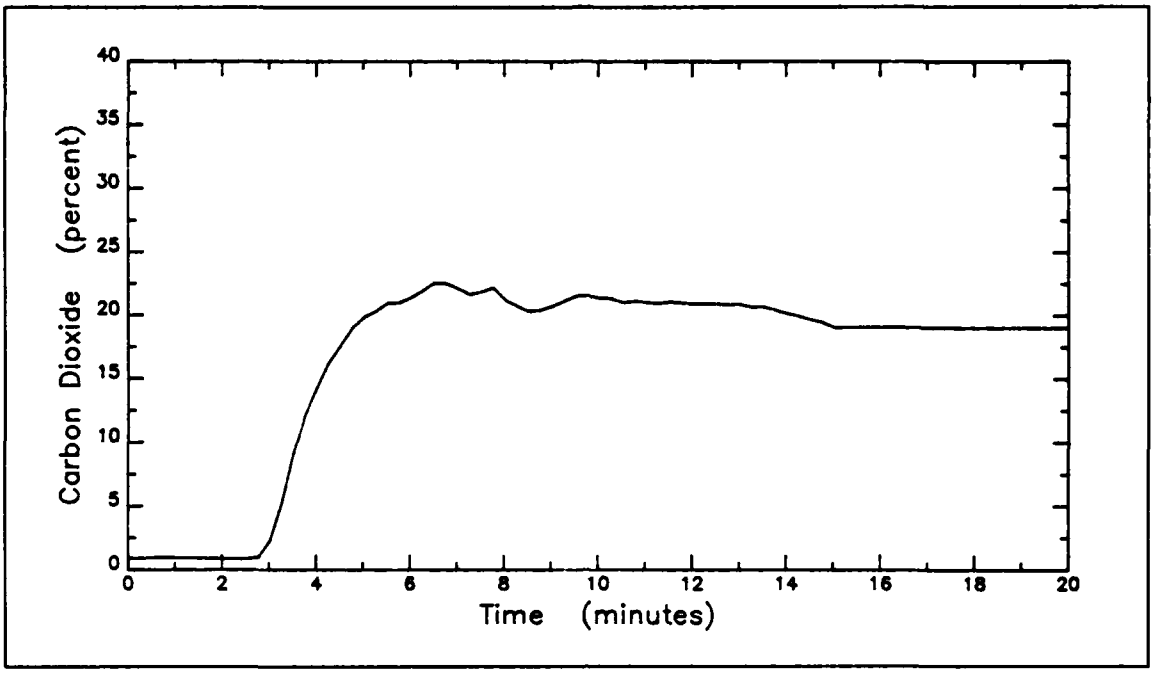



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 10-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

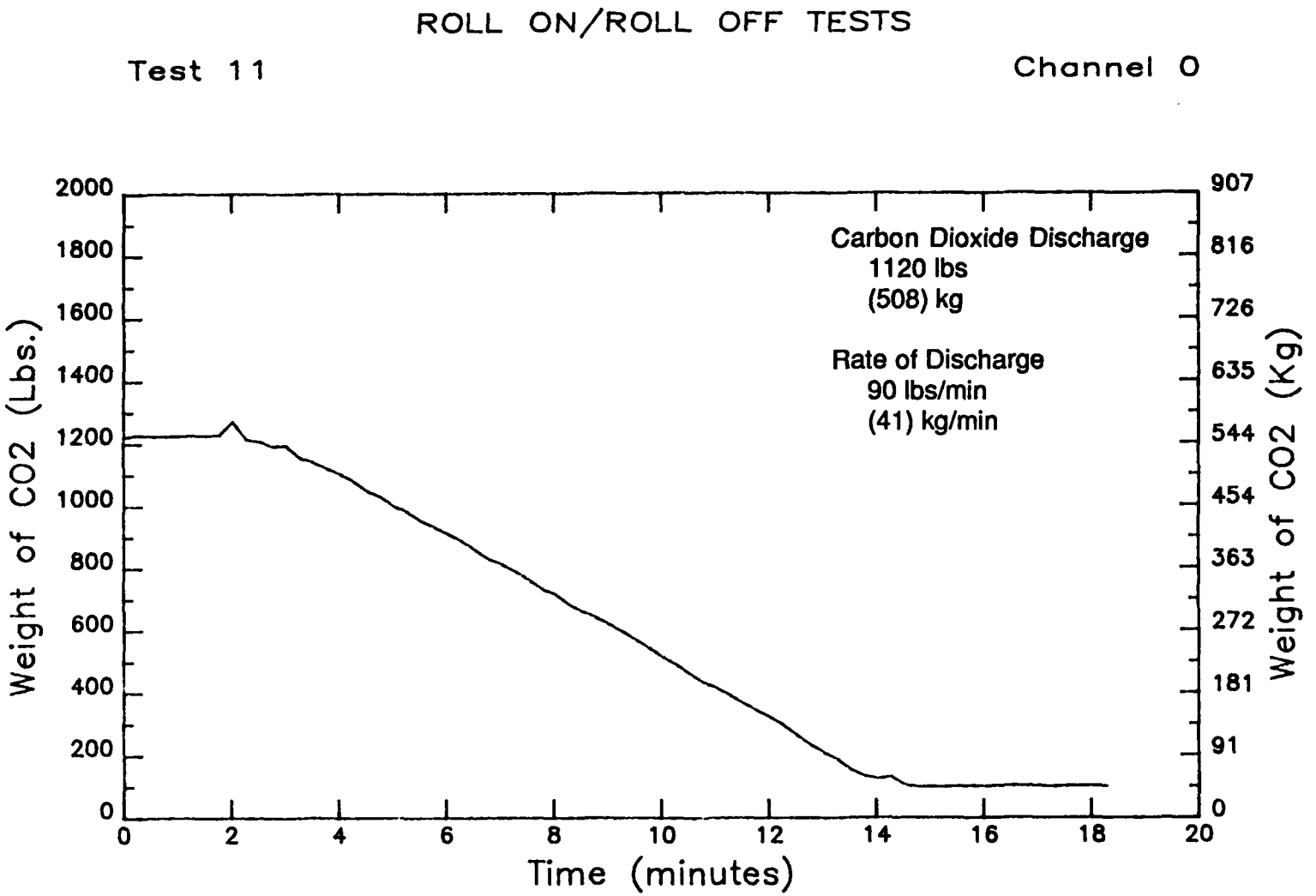



i. Test location - Automobile 3B

**FIGURE B 10-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

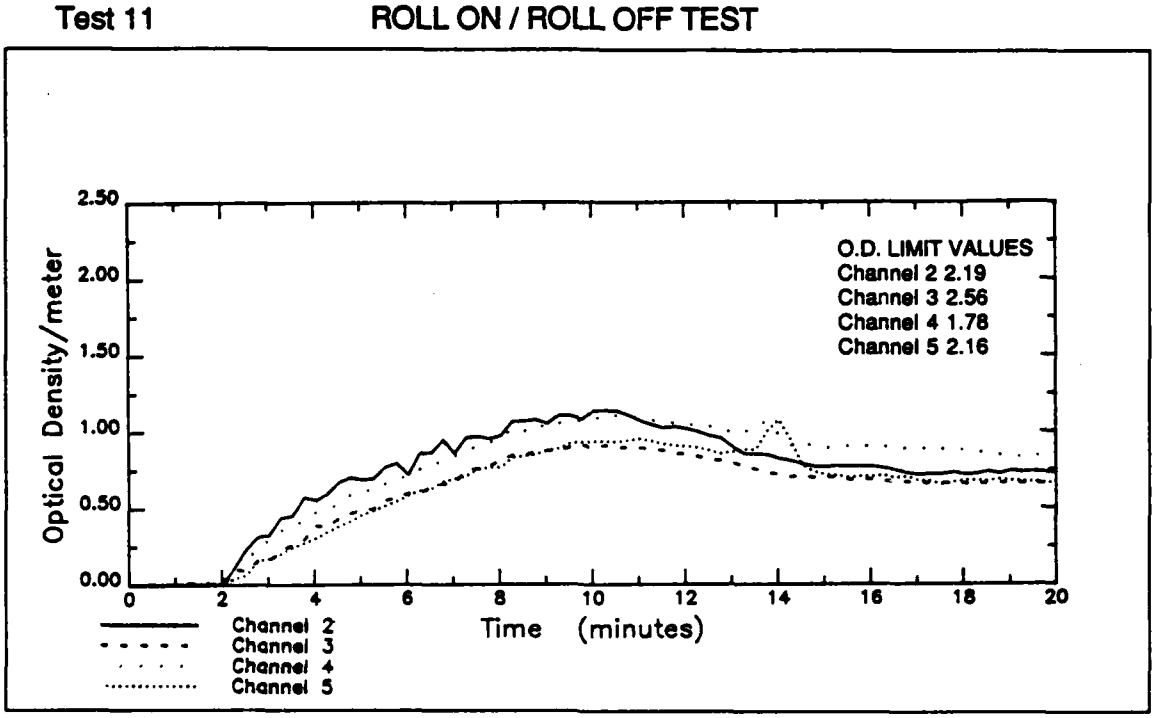
# APPENDIX B

# TEST 11

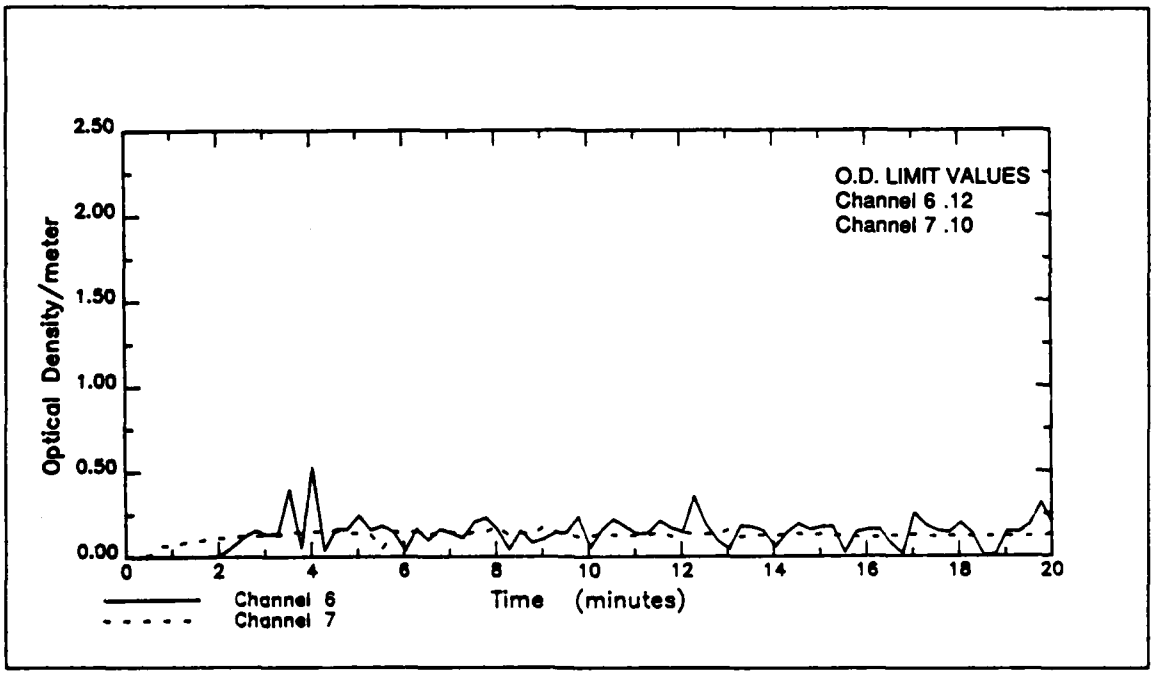



B 11-1

FIGURE B 11-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 11-2. OPTICAL DENSITY vs TIME**

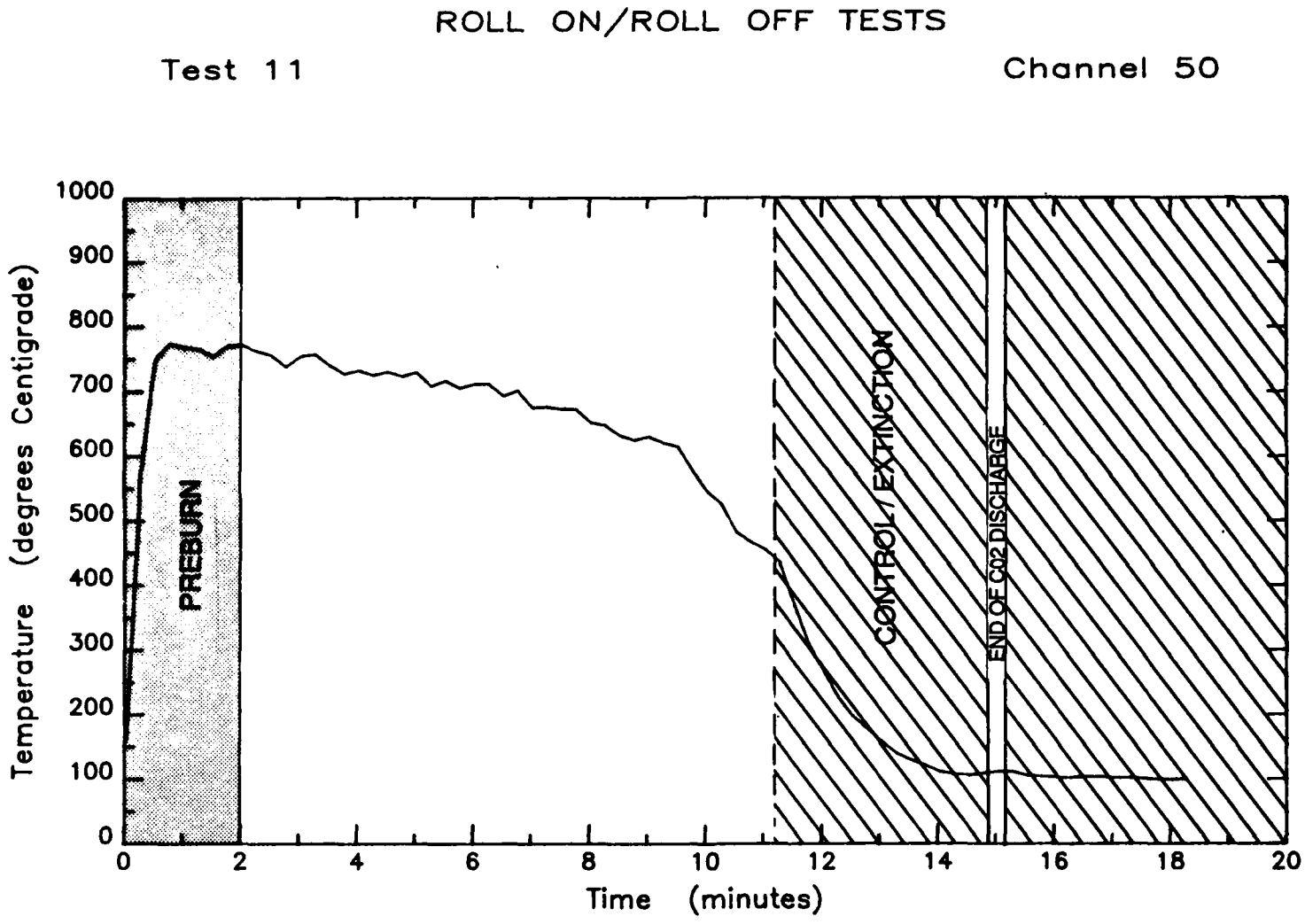
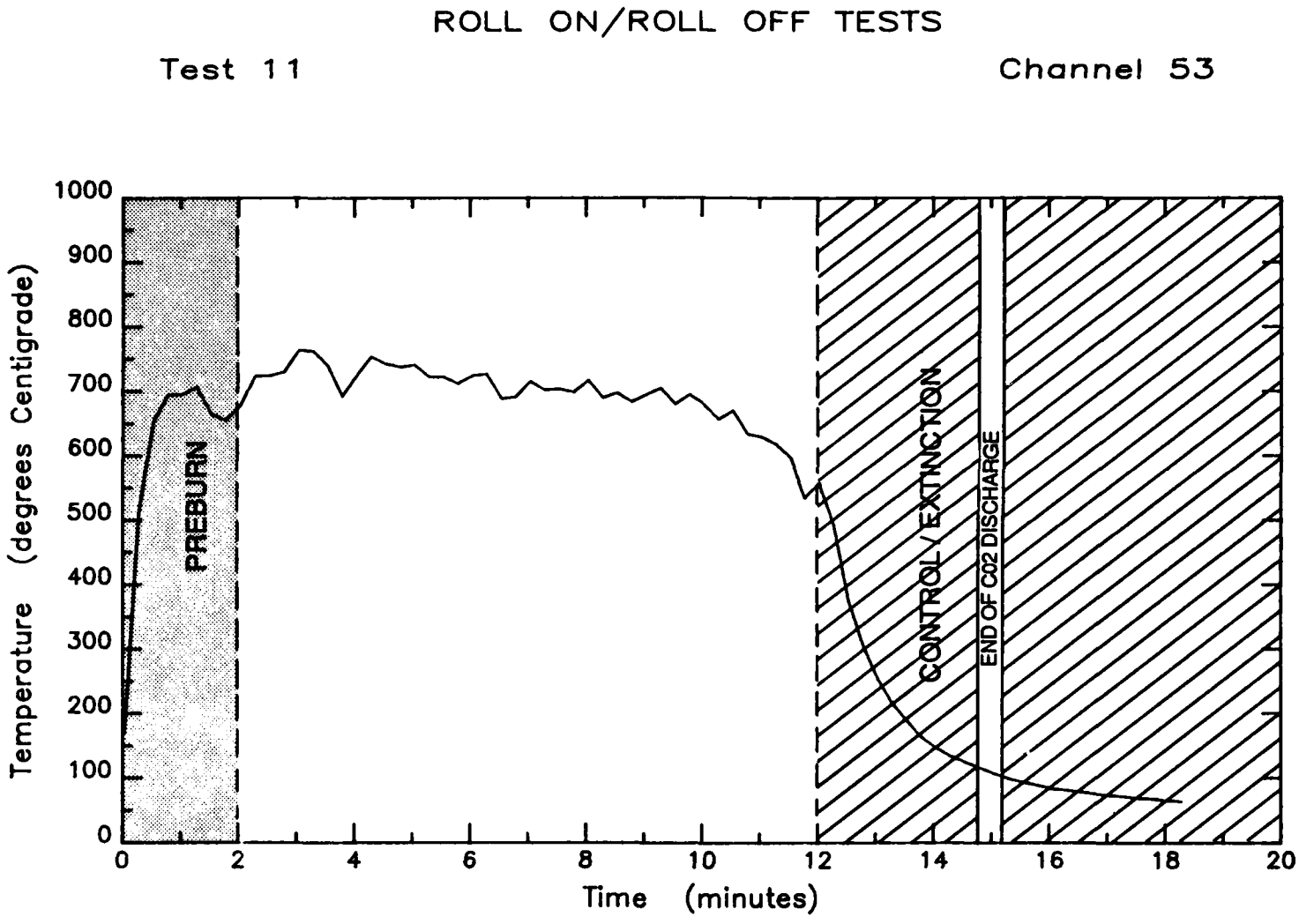



FIGURE B 11-3. Temperature vs Time - Location 9A




B 11-4

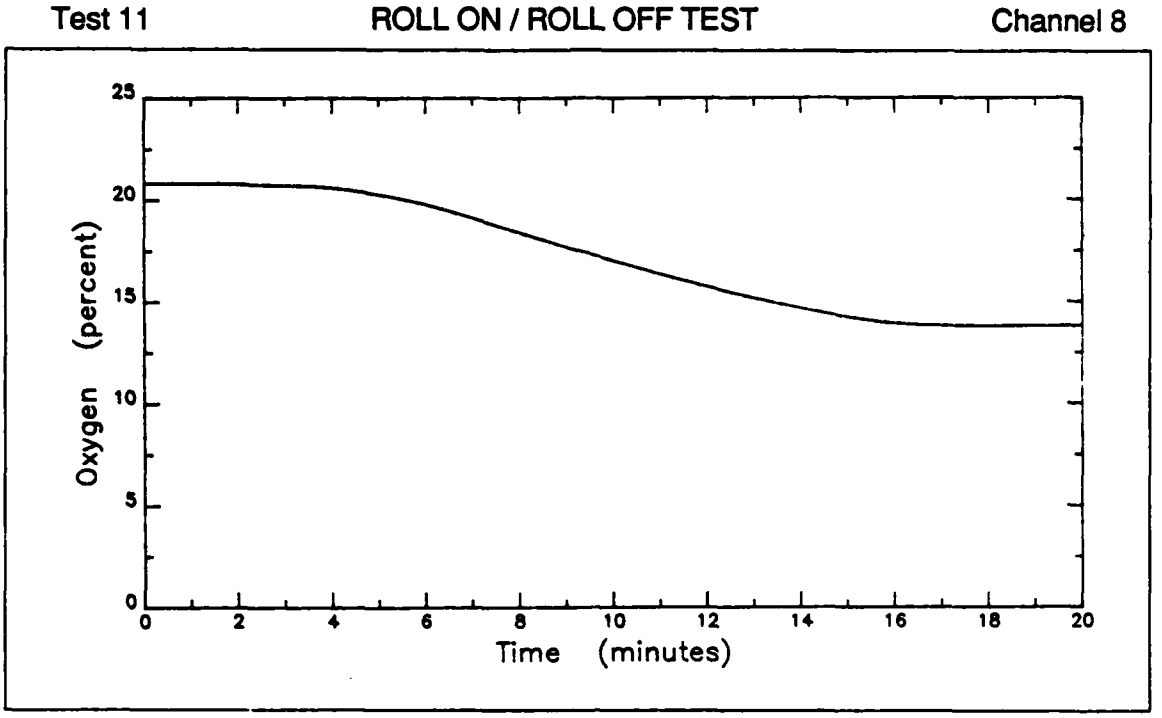
FIGURE B 11-4. Temperature vs Time - Location 10A

TEST 11

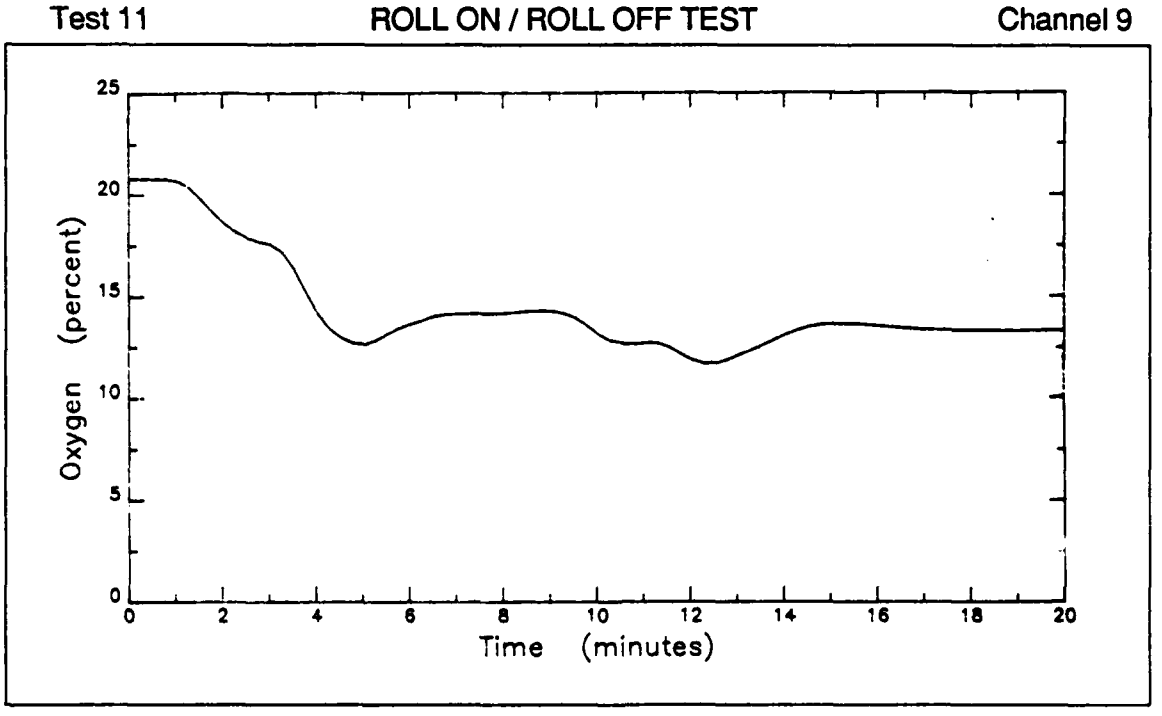
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 11.7 | 15.9 | 18.0 | 13.8 | 14.4% OXYGEN @ 14.6 MINUTES |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 11.7 | 15.9 | 18.0 | 13.7 | 14.4% OXYGEN @ 14.3 MINUTES |
| 11 | Auto 11A | 11.7 | 16.2 | 16.0 | 14.9 | |
| 12 | Auto 9B | 11.7 | 15.8 | 16.5 | 14.8 | |
| 13 | Auto 12B | 11.7 | 17.2 | 16.8 | 16.2 | |
| | | AVERAGE | 16.2 | 17.1 | 14.7 | |



FIGURE B 11-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

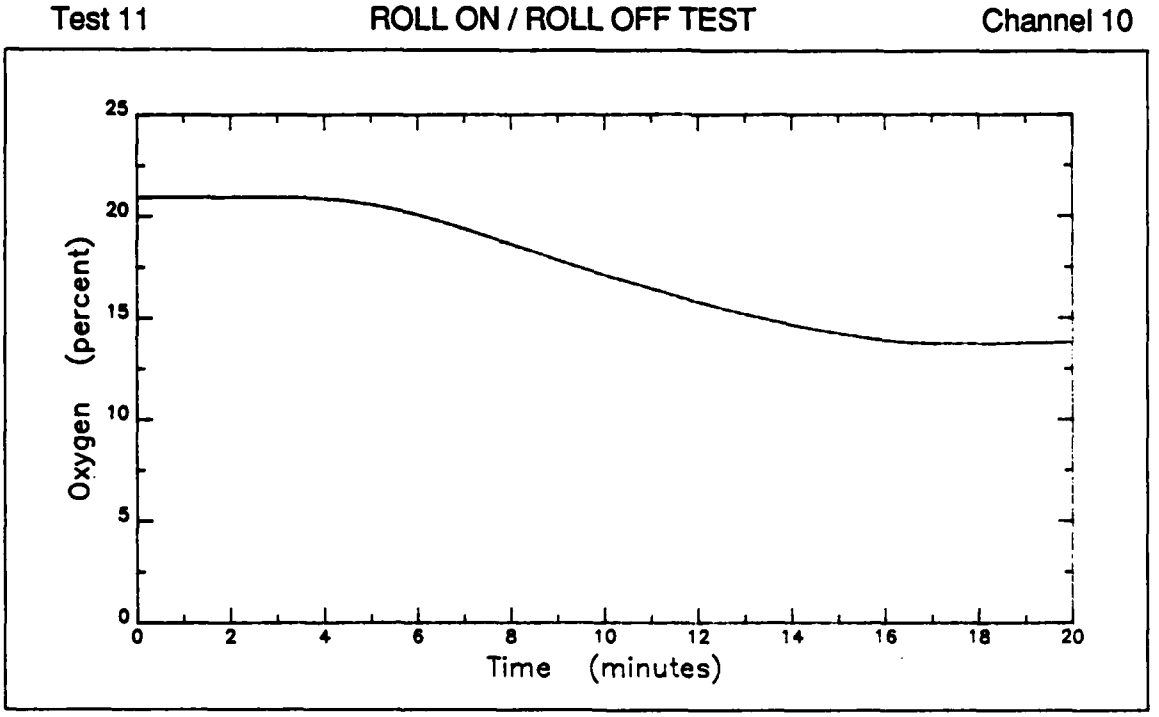



a. Test location - Automobile 9A

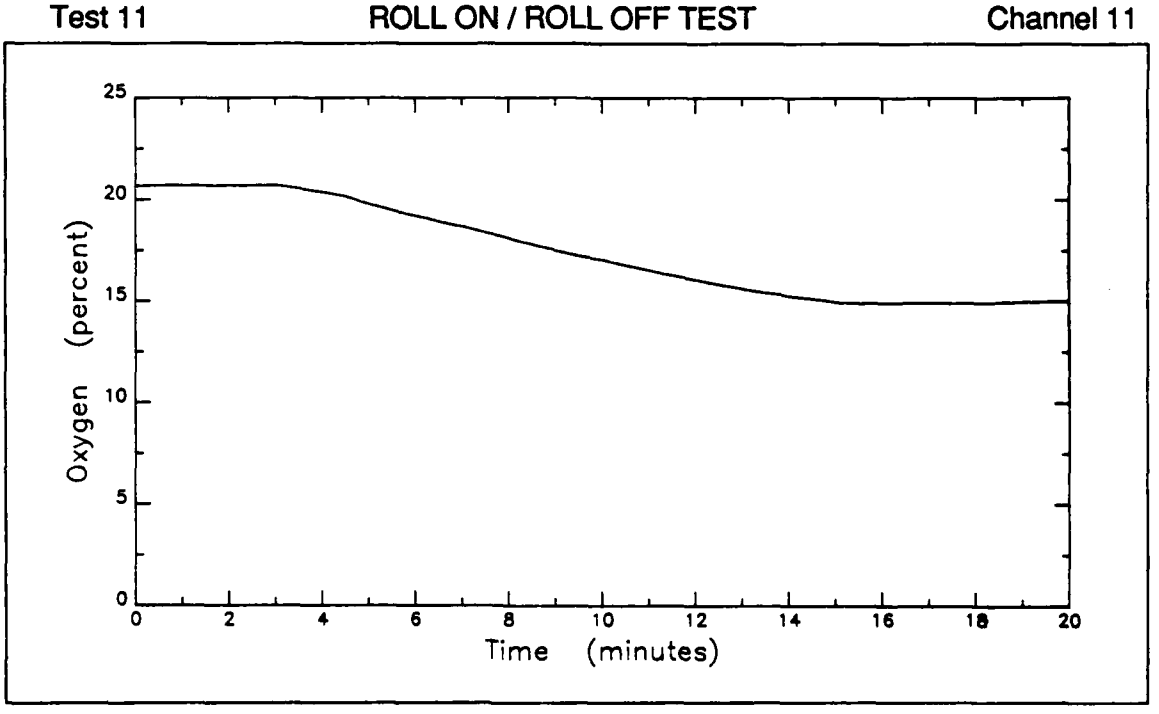



b. Test location - Automobile 10A

**FIGURE B 11-6. PERCENT OXYGEN vs TIME**

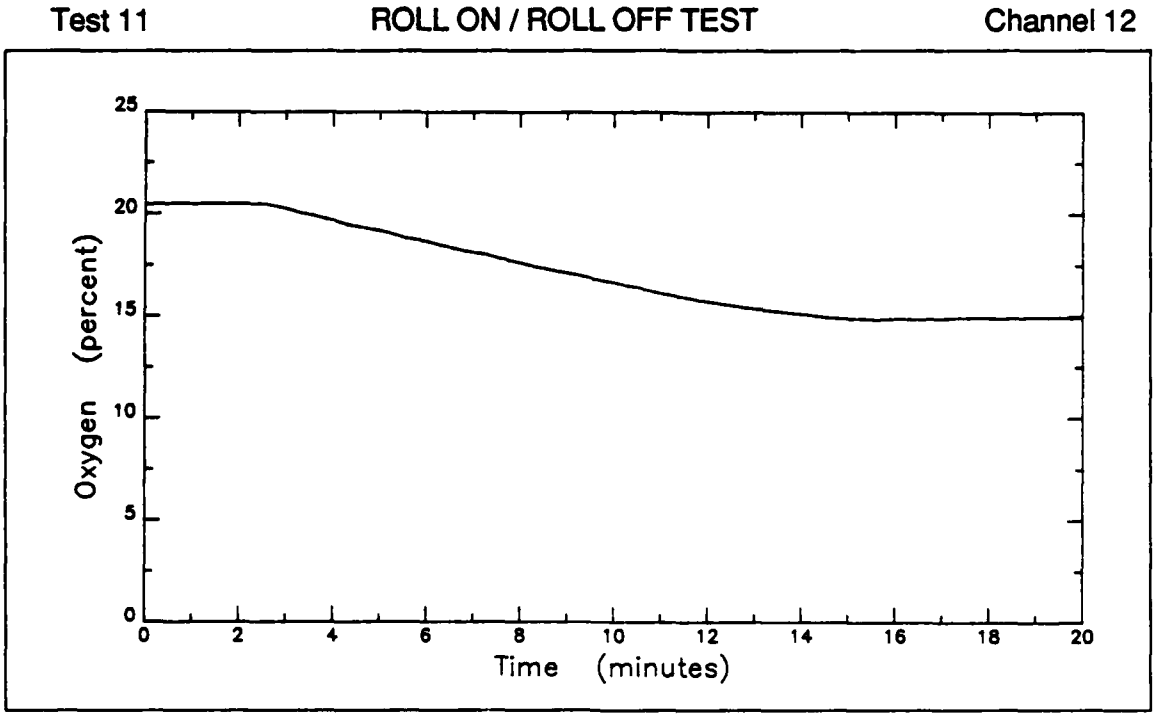



c. Test location - Automobile 11A

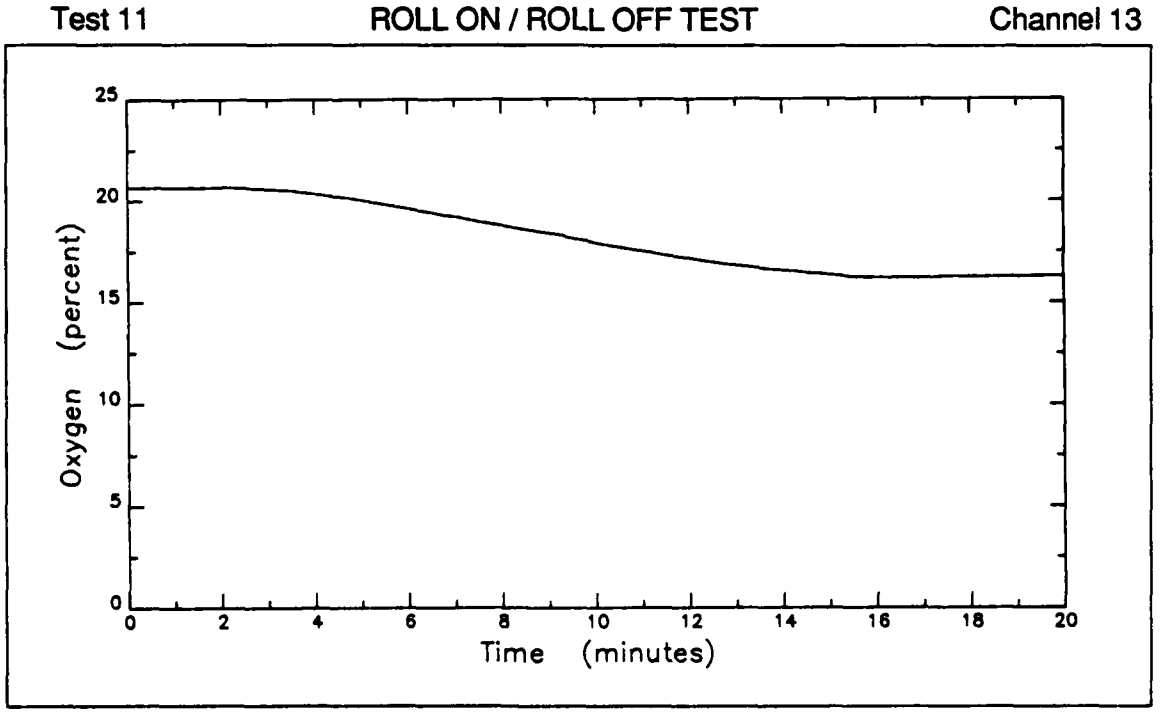



d. Test location - Automobile 12A

**FIGURE B 11-6. PERCENT OXYGEN vs TIME**




e. Test location - Automobile 9B



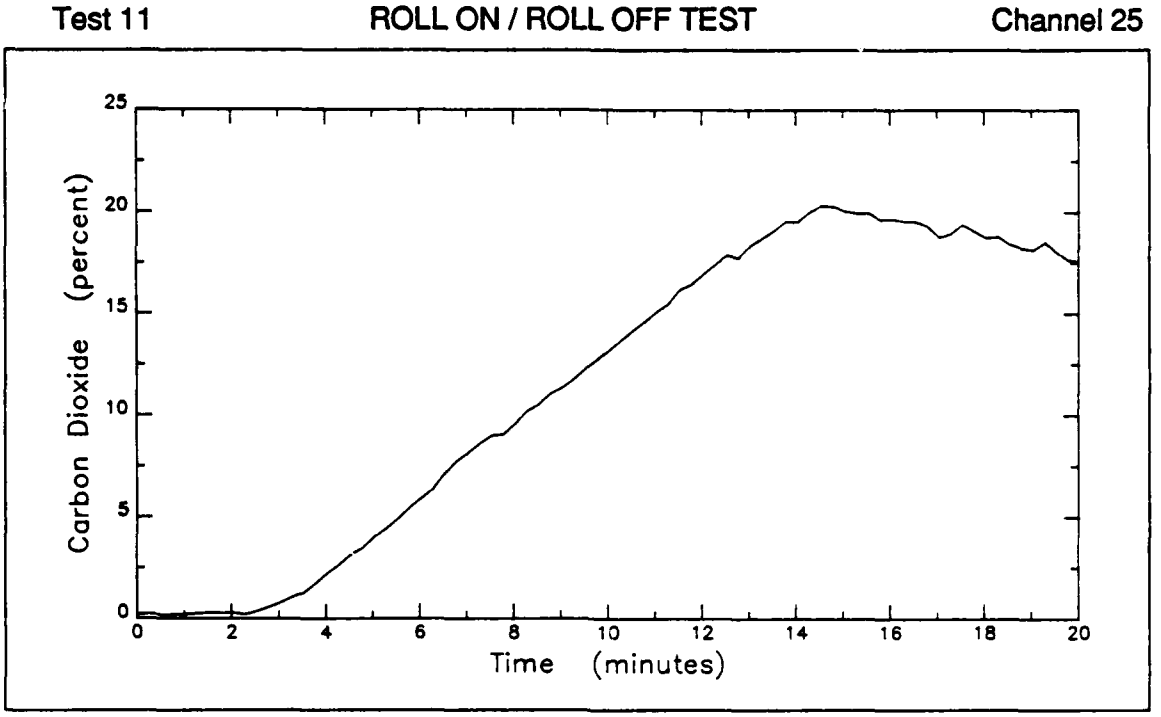

f. Test location - Automobile 12B

**FIGURE B 11-6. PERCENT OXYGEN vs TIME (cont'd)**

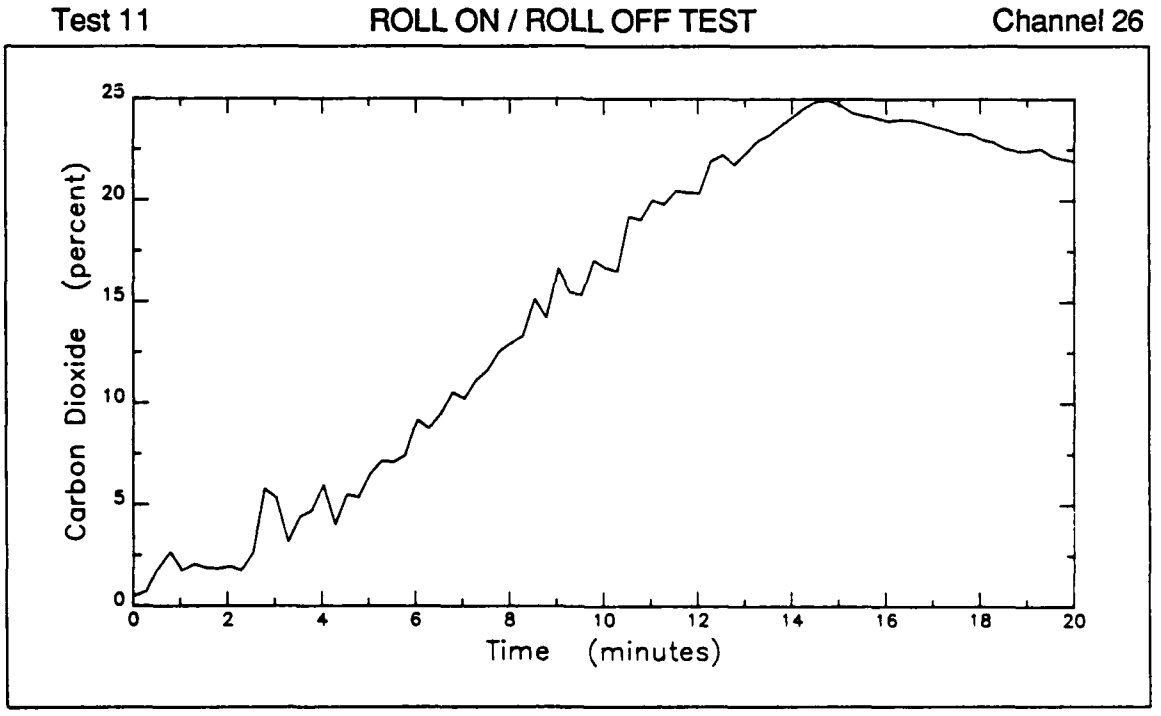
TEST 11

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 11.7 | 16.3 | 14.5 | 20.3 | |
| 26 | Auto 10A | 11.7 | 20.4 | 14.8 | 24.9 | |
| 27 | Auto 11A | 11.7 | 22.7 | 15.0 | 29.9 | |
| 28 | Auto 12A | 11.7 | 24.8 | 16.0 | 31.2 | |
| 29 | Auto 9C | 11.7 | 17.8 | 14.8 | 23.0 | |
| 30 | Auto 3A | 11.7 | 16.5 | 15.5 | 22.0 | |
| 31 | Auto 9B | 11.7 | 22.8 | 15.5 | 32.1 | |
| 32 | Auto 12B | 11.7 | 23.0 | 20.0 | 34.5 | |
| 33 | Auto 3B | 11.7 | 2.8 | 20.0 | 14.3 | |
| | | AVERAGE | 18.6 | 15.2 | 26.2 | |

FIGURE B 11-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

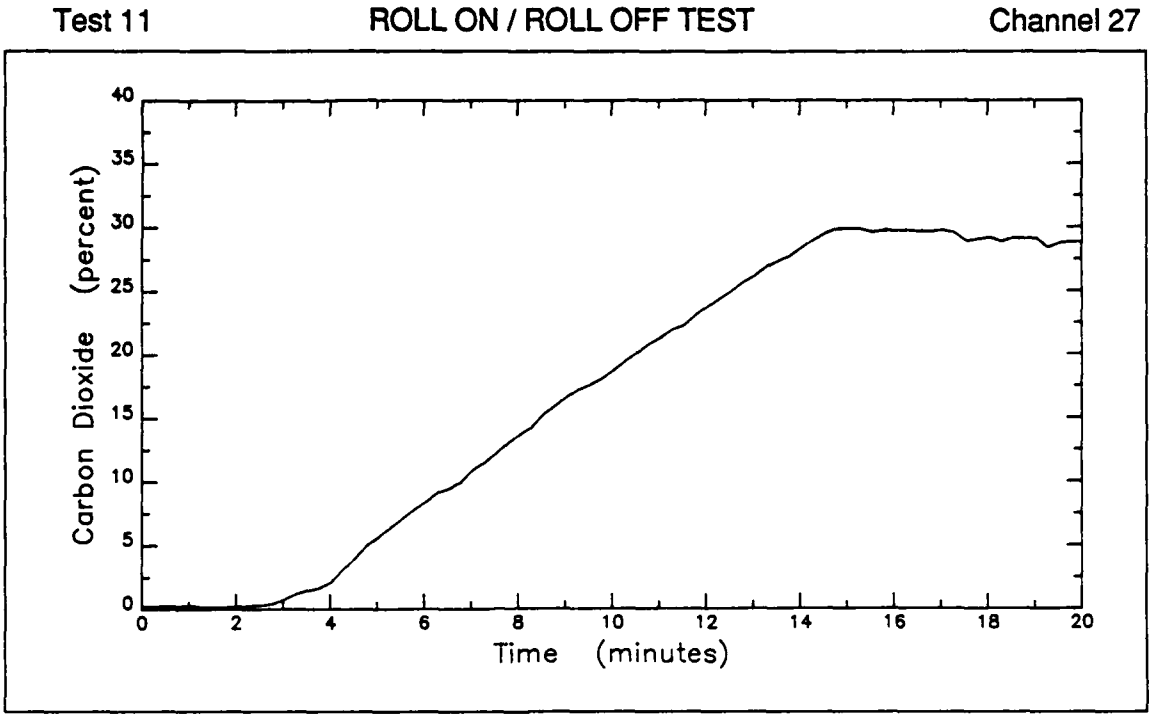



a. Test location - Automobile 9A

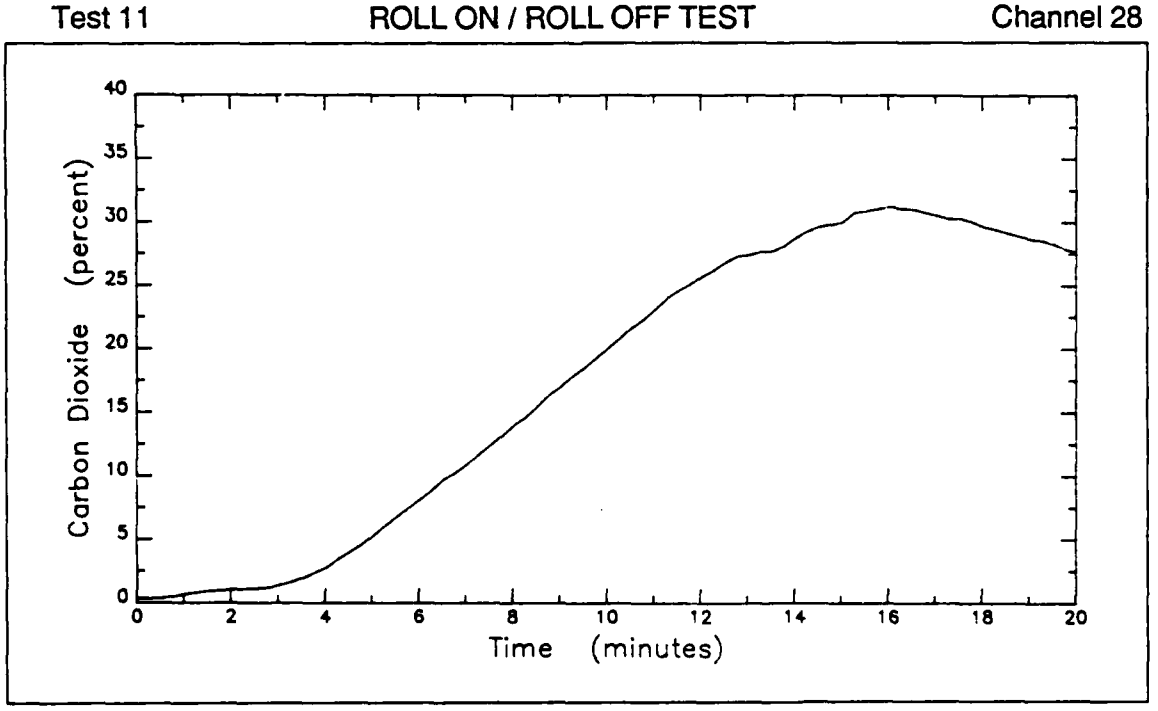



b. Test location - Automobile 10A

**FIGURE B 11-8. PERCENT CARBON DIOXIDE vs TIME**

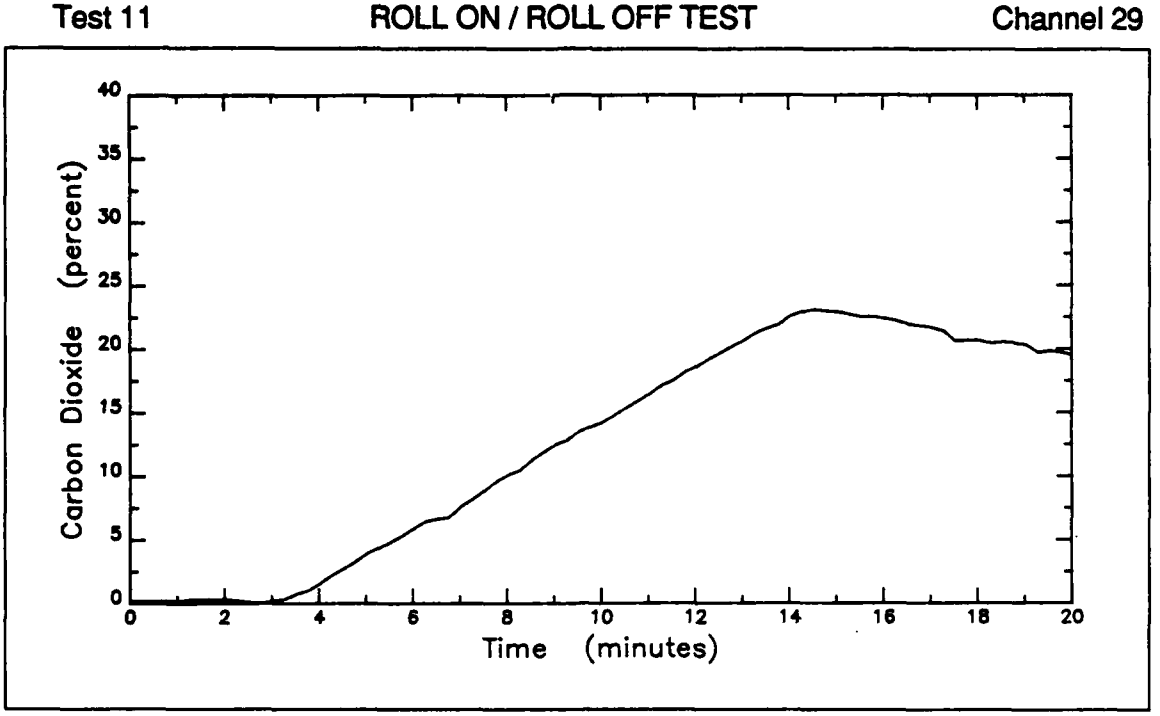



c. Test location - Automobile 11A

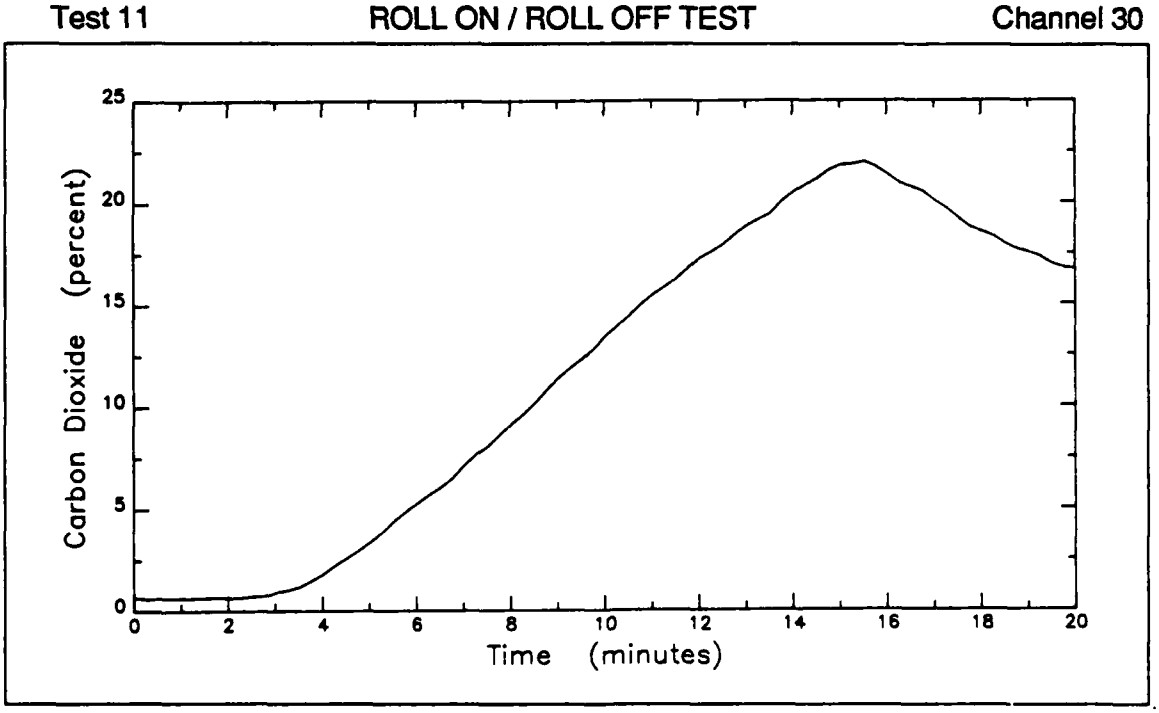



d. Test location - Automobile 12A

**FIGURE B 11-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

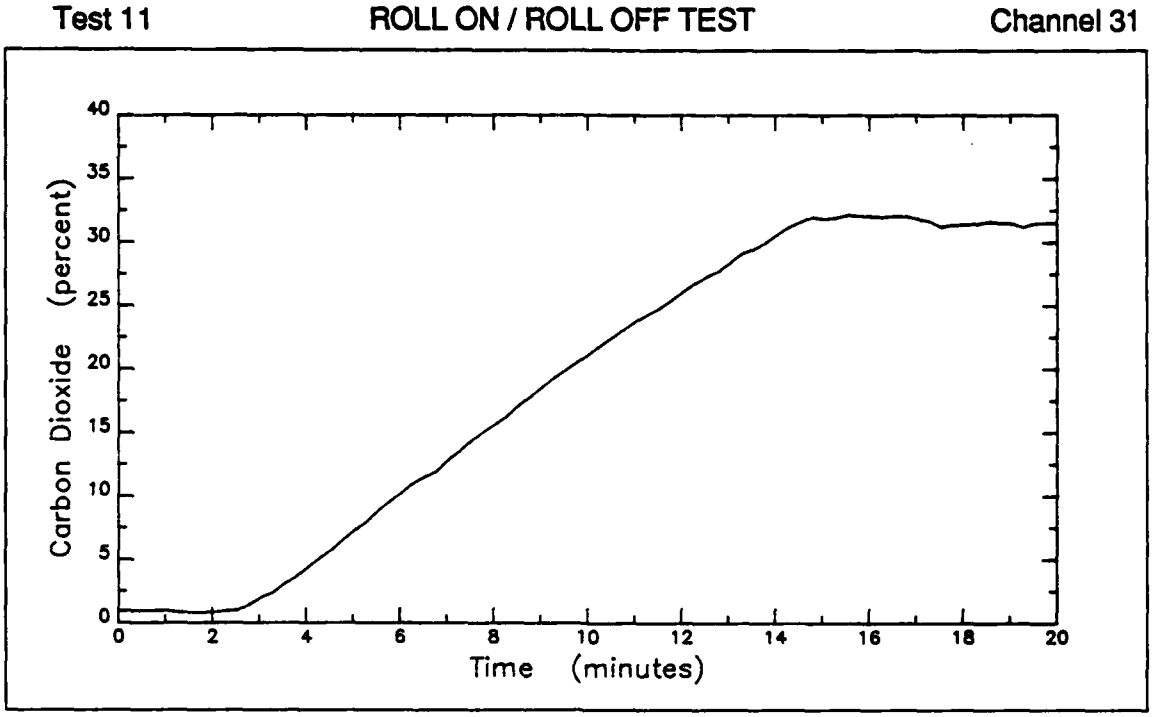



e. Test location - Automobile 9C

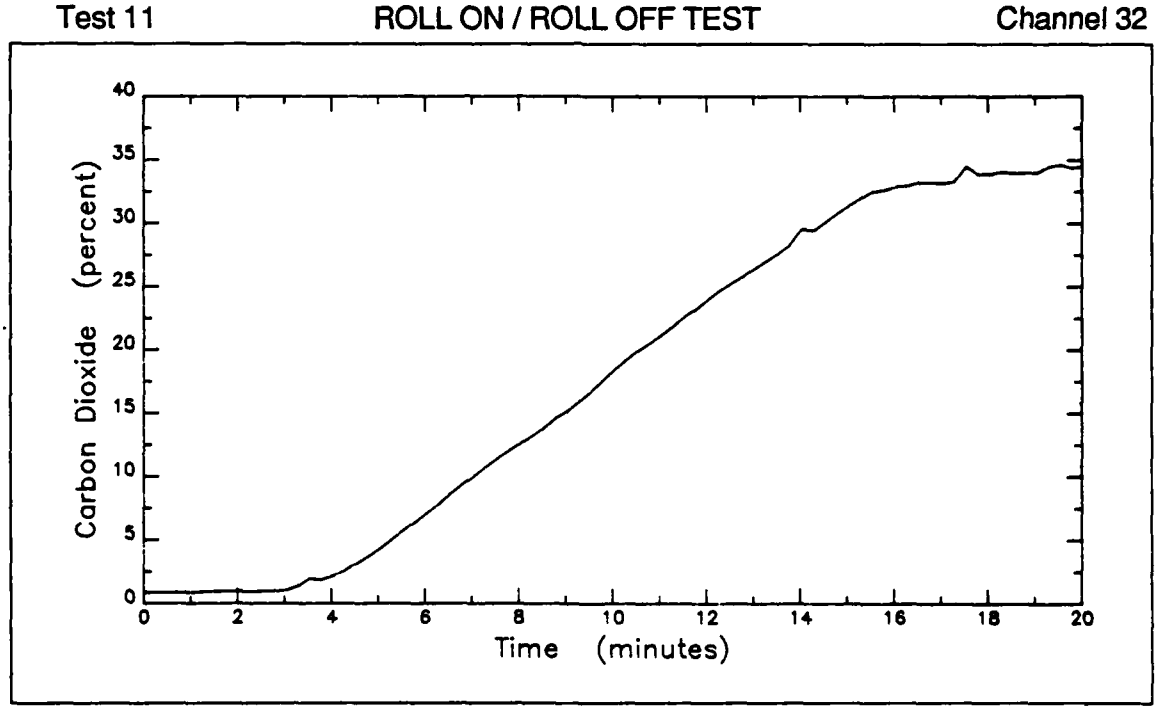



f. Test location - Automobile 3A

**FIGURE B 11-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

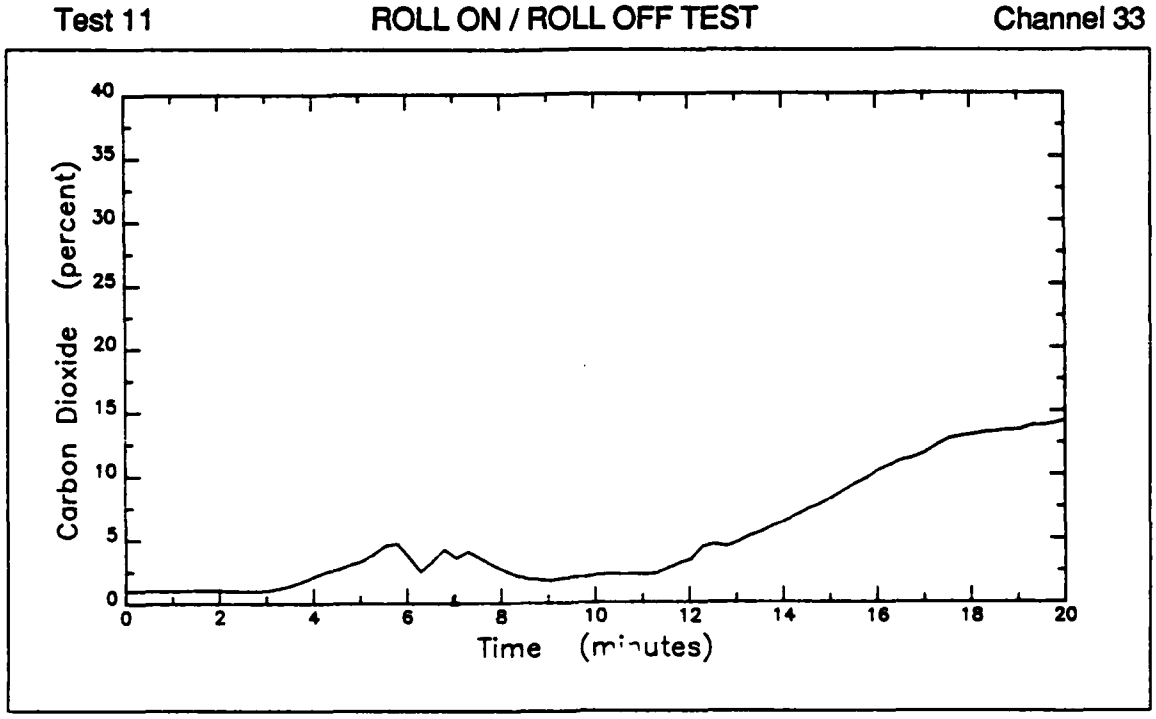



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 11-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

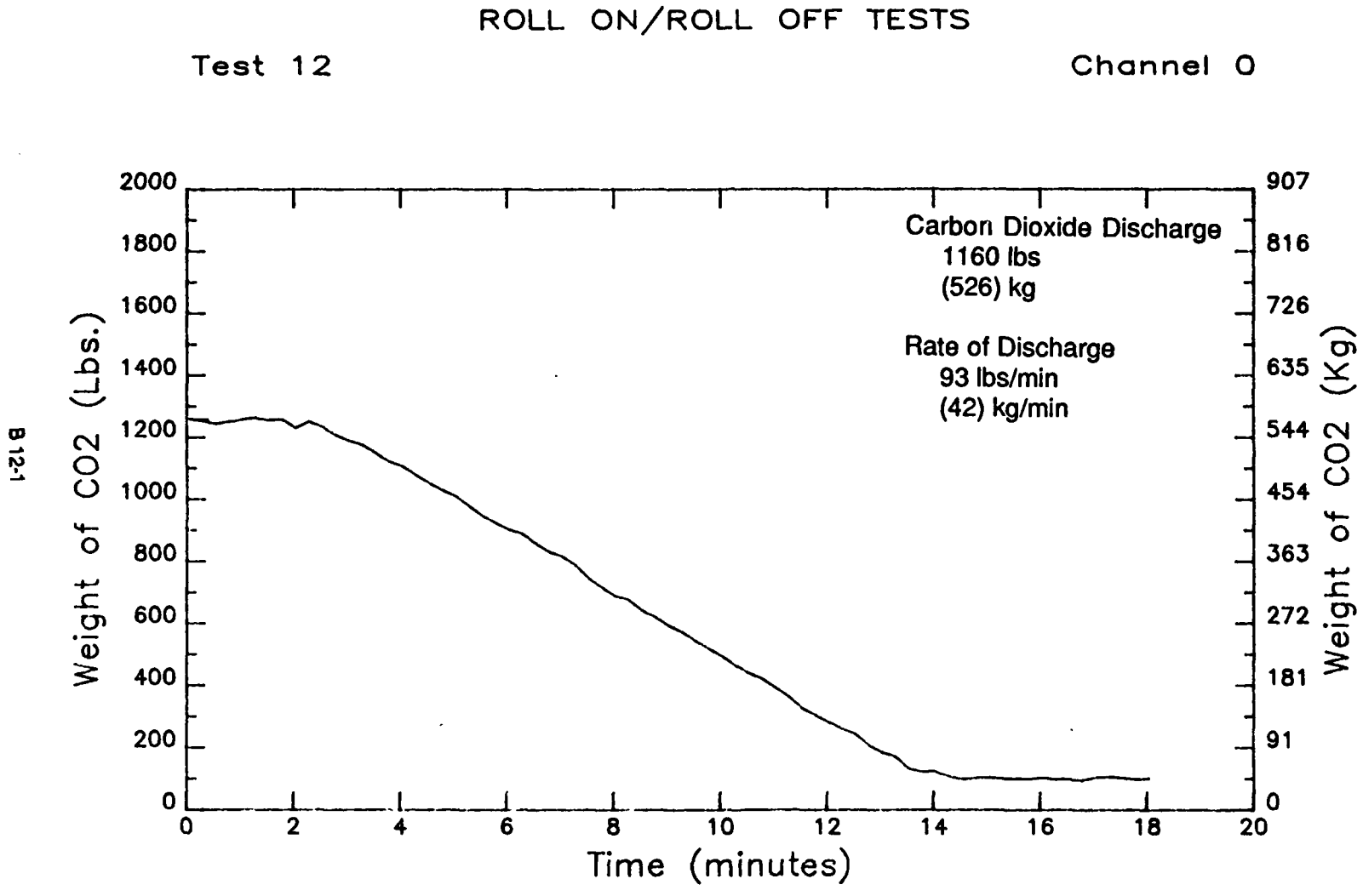



i. Test location - Automobile 3B

**FIGURE B 11-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

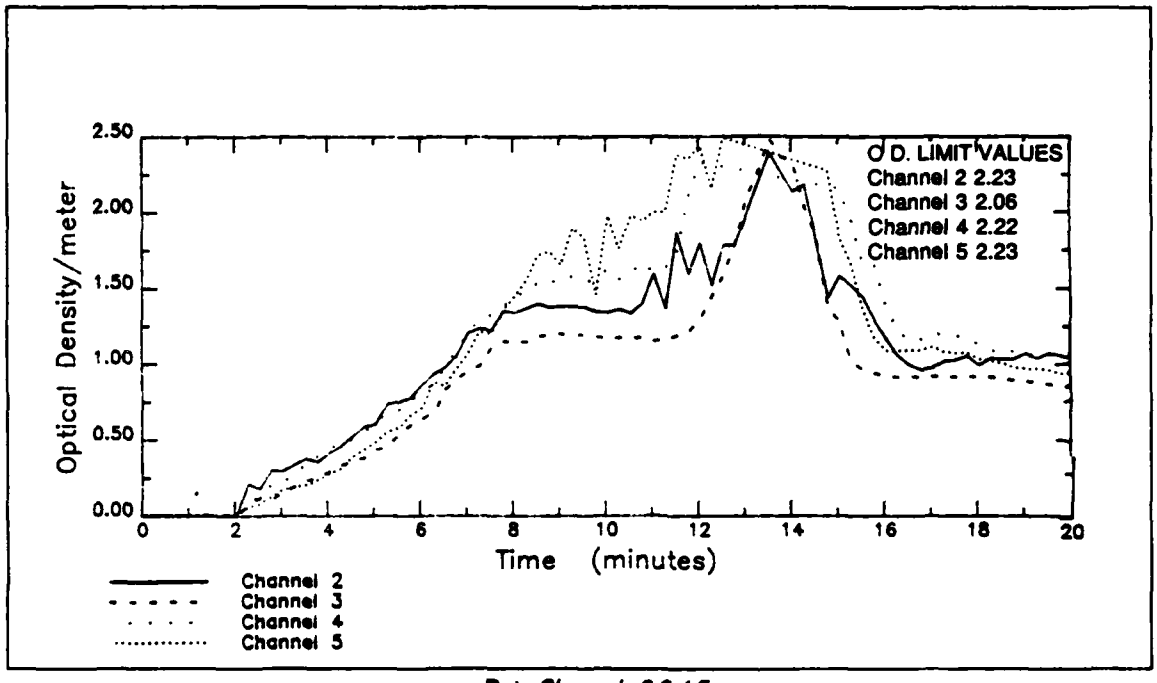
# TEST 12




B 12-1

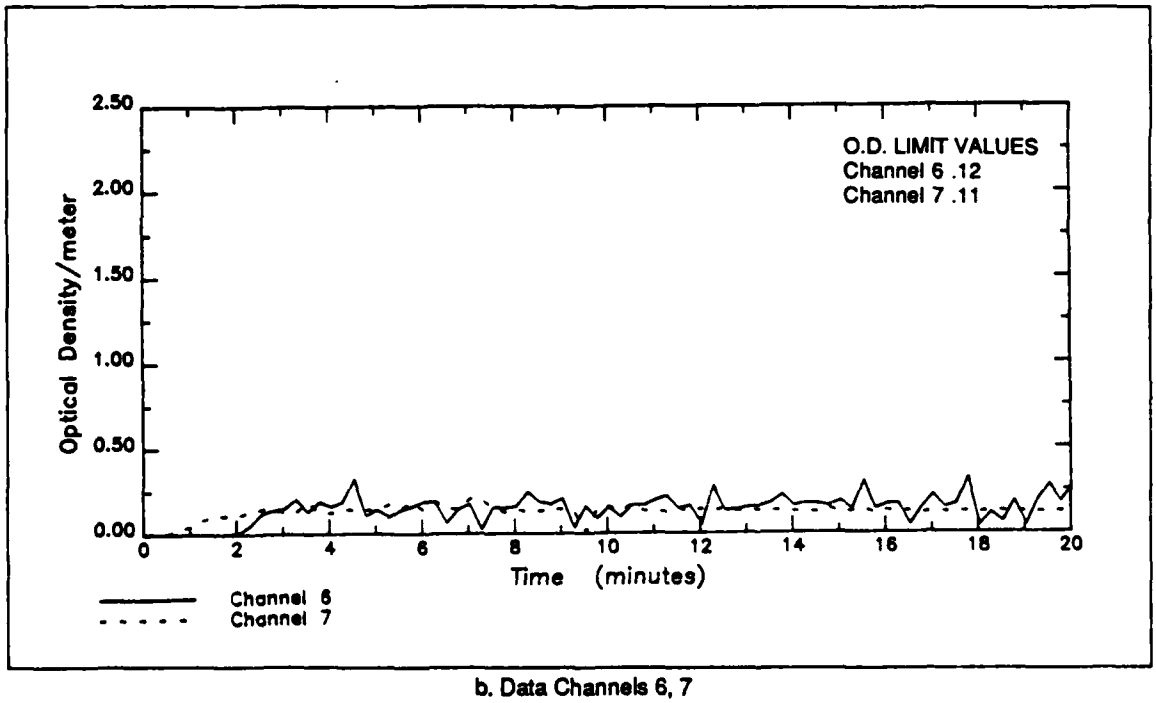
FIGURE B 12-1. Weight of Carbon Dioxide vs Time

Test 12 ROLL ON / ROLL OFF TEST




a. Data Channels 2,3,4,5

Test 12 ROLL ON / ROLL OFF TEST




b. Data Channels 6, 7

**FIGURE 12-2. OPTICAL DENSITY vs TIME**

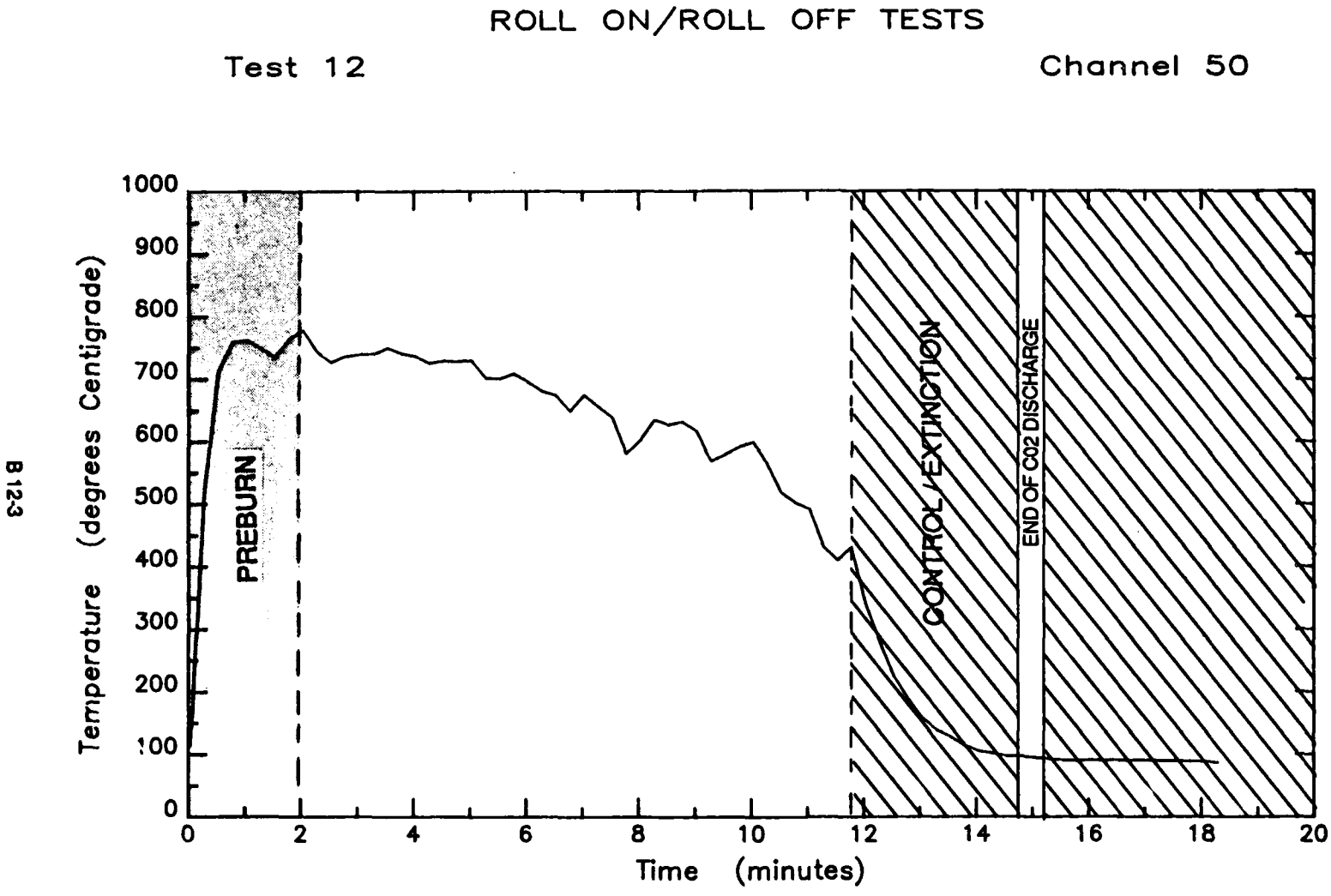
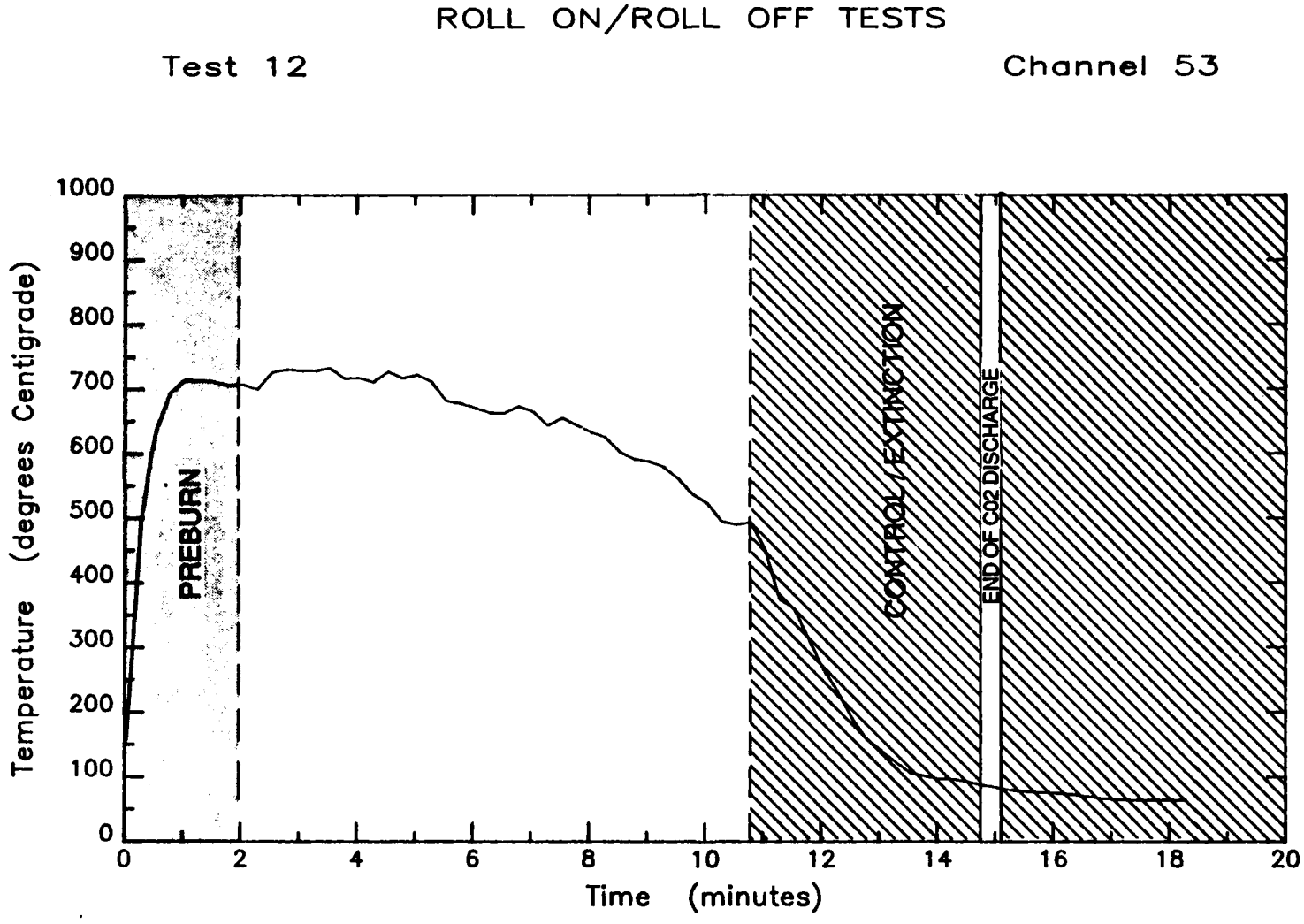



FIGURE B 12-3. Temperature vs Time - Location 9A




B 12-4

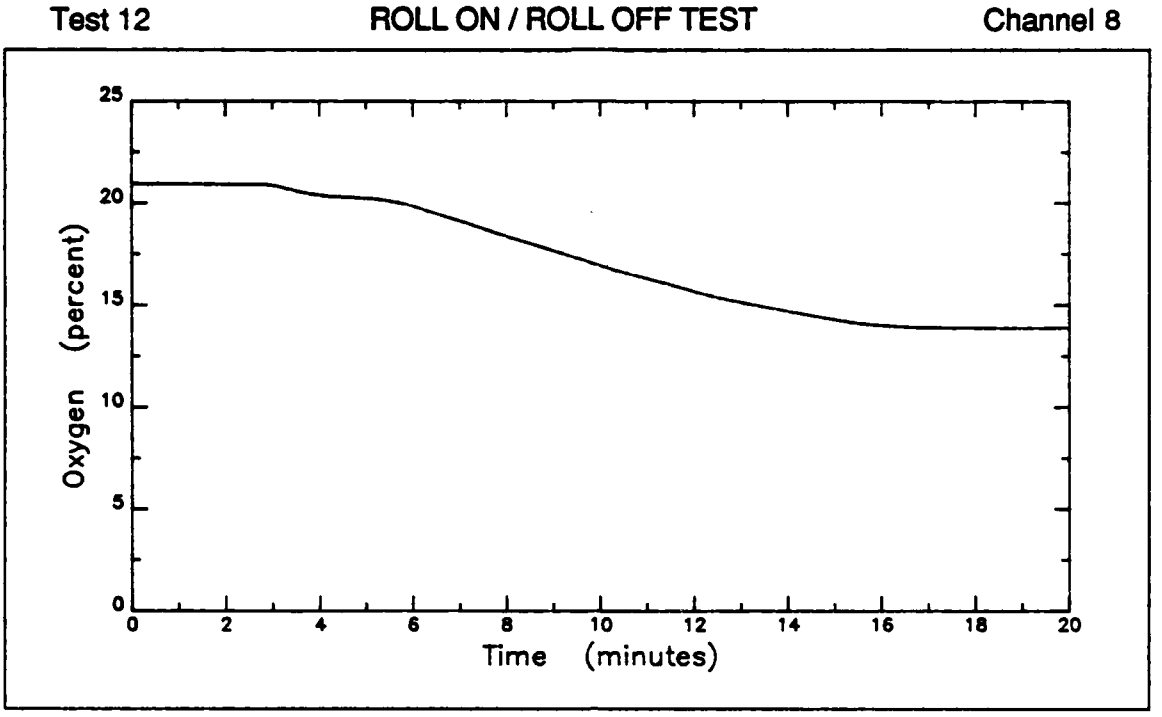
FIGURE B 12-4. Temperature vs Time - Location 10A

TEST 12

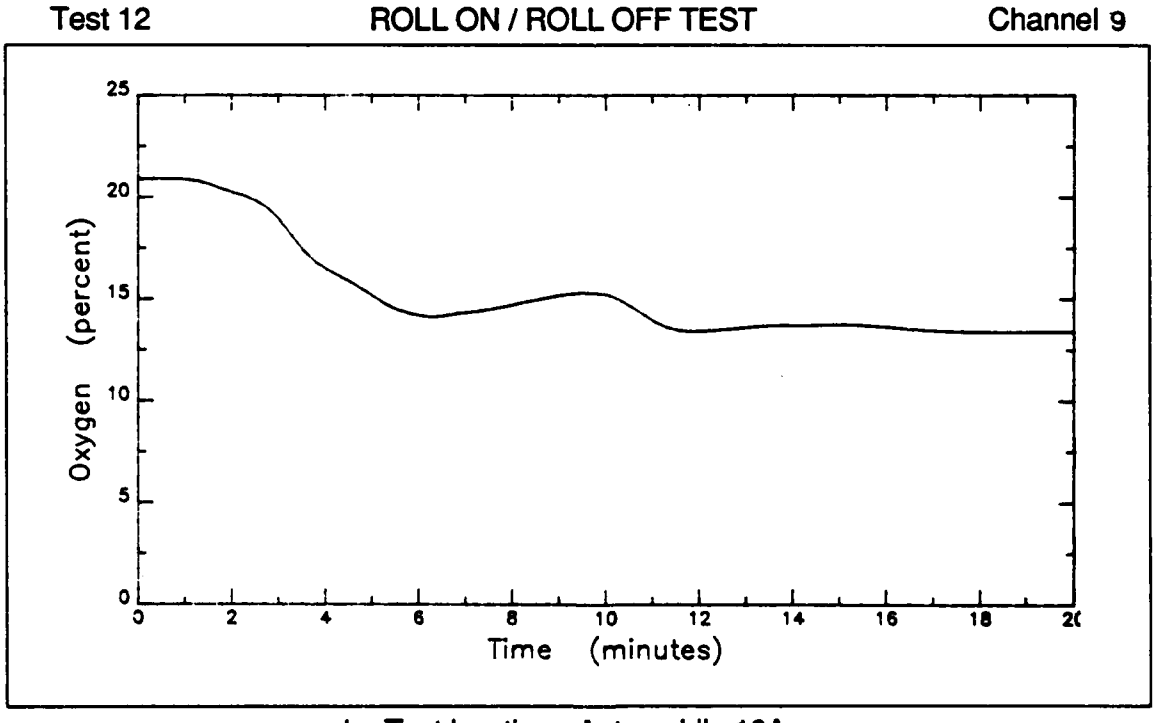
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 11.3 | 16.0 | 18.8 | 13.9 | 14.4% OXYGEN @ 14.6 MINUTES |
| 9 | Auto 10A | 11.3 | -- | -- | -- | |
| 10 | Auto 12A | 11.3 | 16.1 | 18.8 | 13.8 | 14.4 % OXYGEN @ 14.8 MINUTES |
| 11 | Auto 11A | 11.3 | 16.2 | 15.3 | 14.9 | |
| 12 | Auto 9B | 11.3 | 15.8 | 15.5 | 14.4 | |
| 13 | Auto 12B | 11.3 | 17.3 | 15.5 | 16.3 | |
| | | AVERAGE | 16.3 | 16.8 | 14.8 | |



FIGURE B 12-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

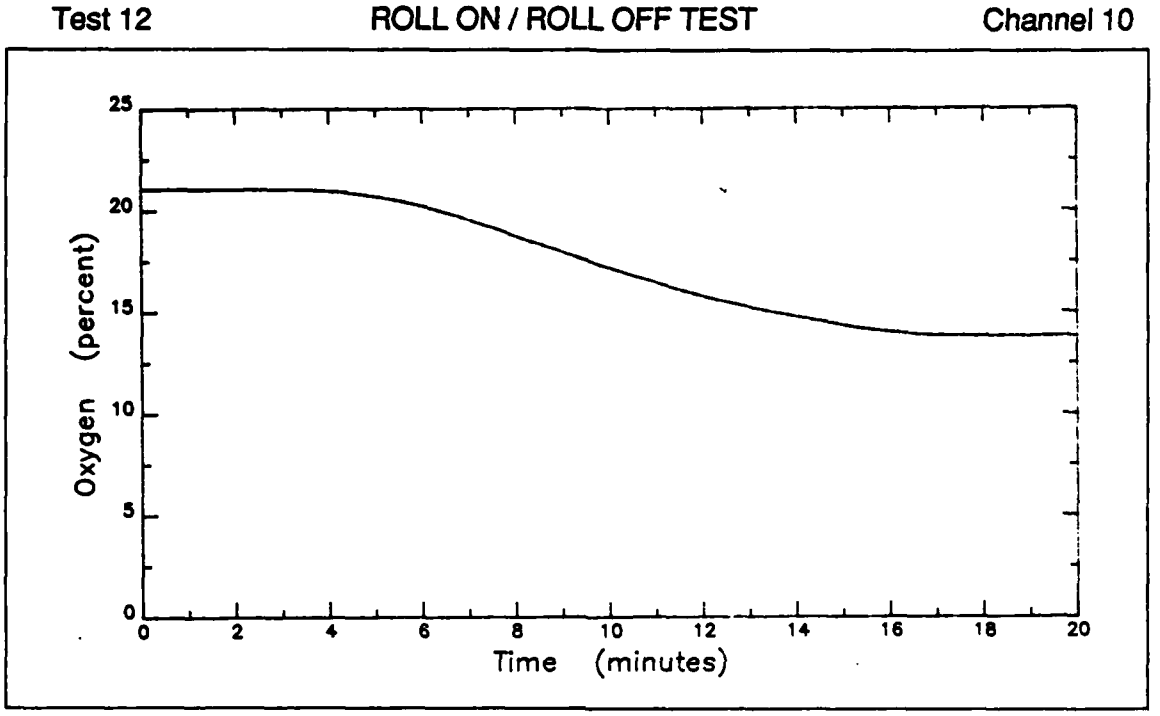



a. Test location - Automobile 9A

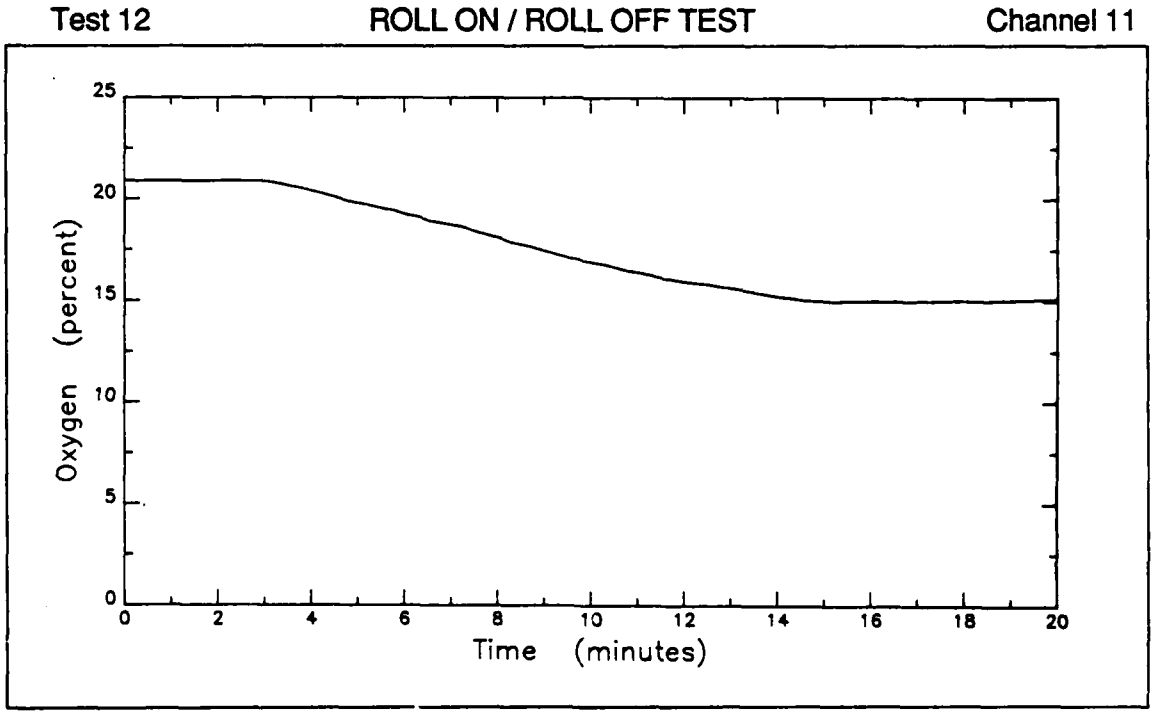



b. Test location - Automobile 10A

**FIGURE B 12-6. PERCENT OXYGEN vs TIME**

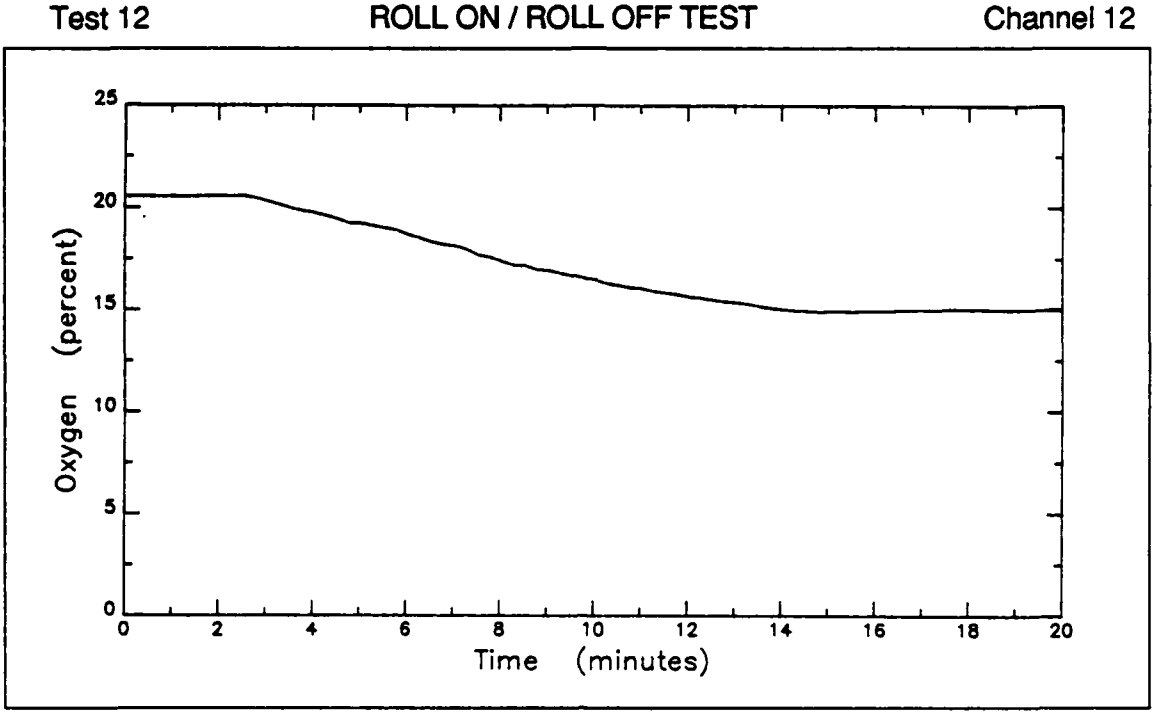



c. Test location - Automobile 11A

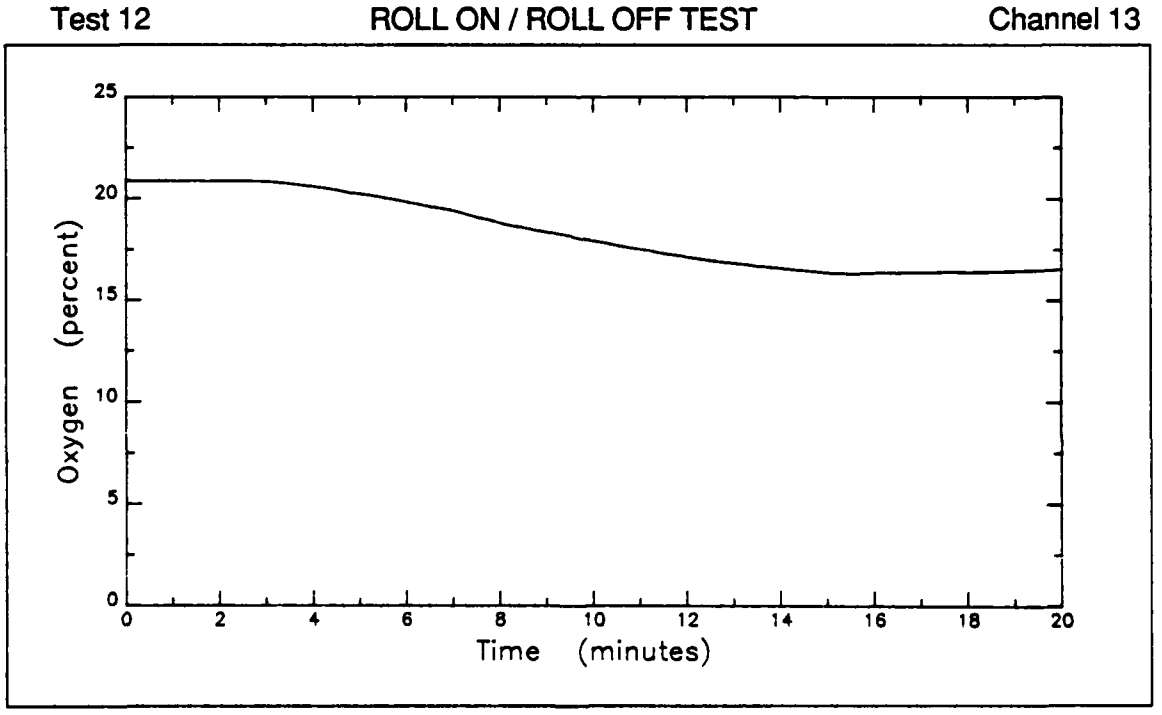



d. Test location - Automobile 12A

**FIGURE B 12-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B



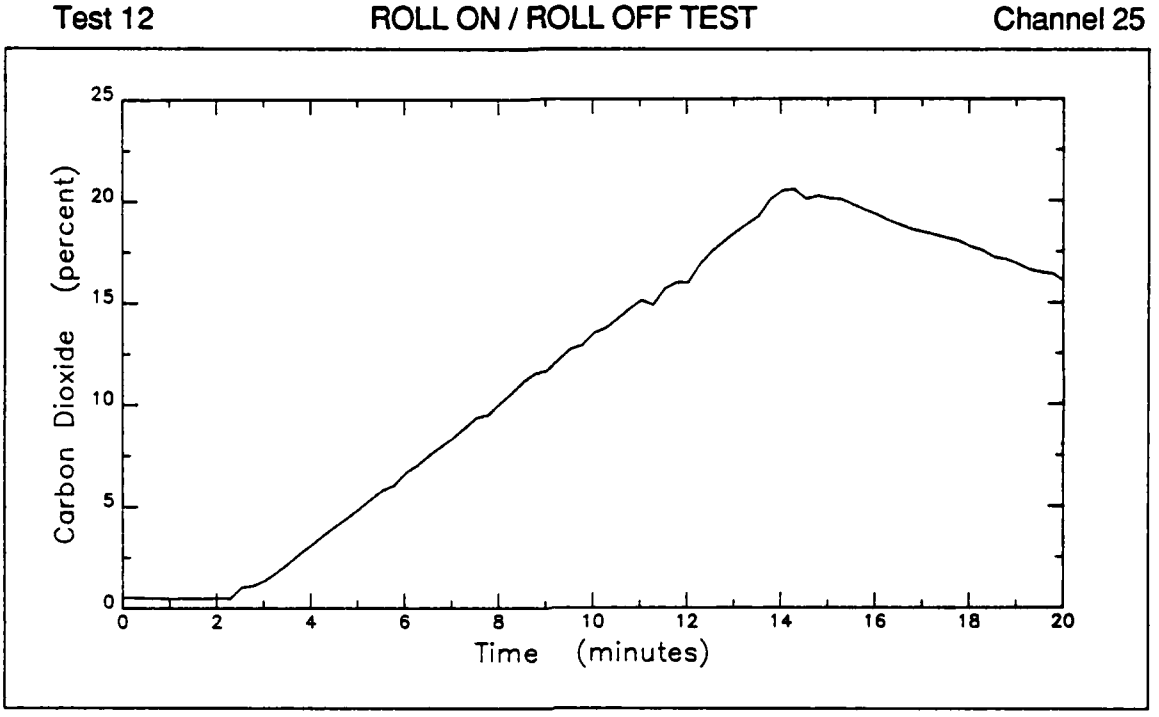

f. Test location - Automobile 12B

**FIGURE B 12-6. PERCENT OXYGEN vs TIME (cont'd)**

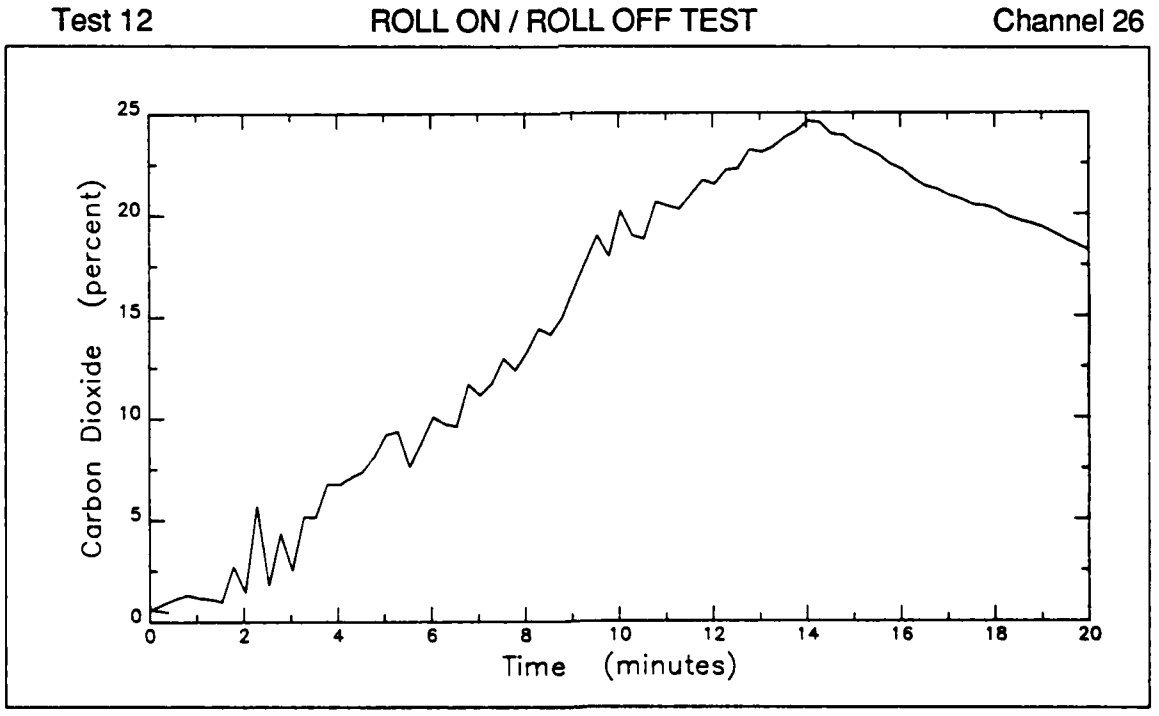
TEST 12

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 11.3 | 14.9 | 14.8 | 20.2 | |
| 26 | Auto 10A | 11.3 | 20.3 | 14.0 | 24.6 | |
| 27 | Auto 11A | 11.3 | 22.6 | 18.5 | 28.7 | |
| 28 | Auto 12A | 11.3 | 19.7 | 14.3 | 23.3 | |
| 29 | Auto 9C | 11.3 | 17.6 | 16.3 | 21.6 | |
| 30 | Auto 3A | 11.3 | 13.0 | 17.1 | 15.8 | |
| 31 | Auto 9B | 11.3 | 24.9 | 16.5 | 31.1 | |
| 32 | Auto 12B | 11.3 | 22.1 | 20.0 | 32.9 | |
| 33 | Auto 3B | 11.3 | 1.8* | 20.0 | 13.0 | *See Page B-12-14 |
| | | AVERAGE | 16.9 | 15.9 | 23.6 | |

FIGURE B 12-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

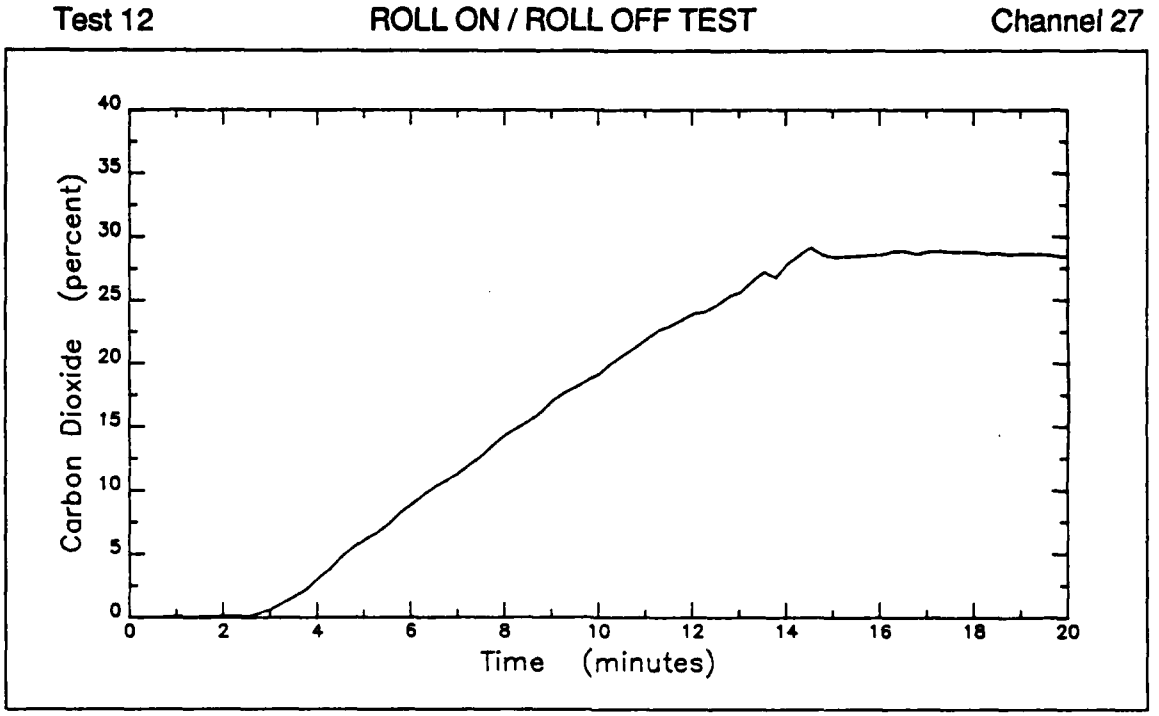



a. Test location - Automobile 9A

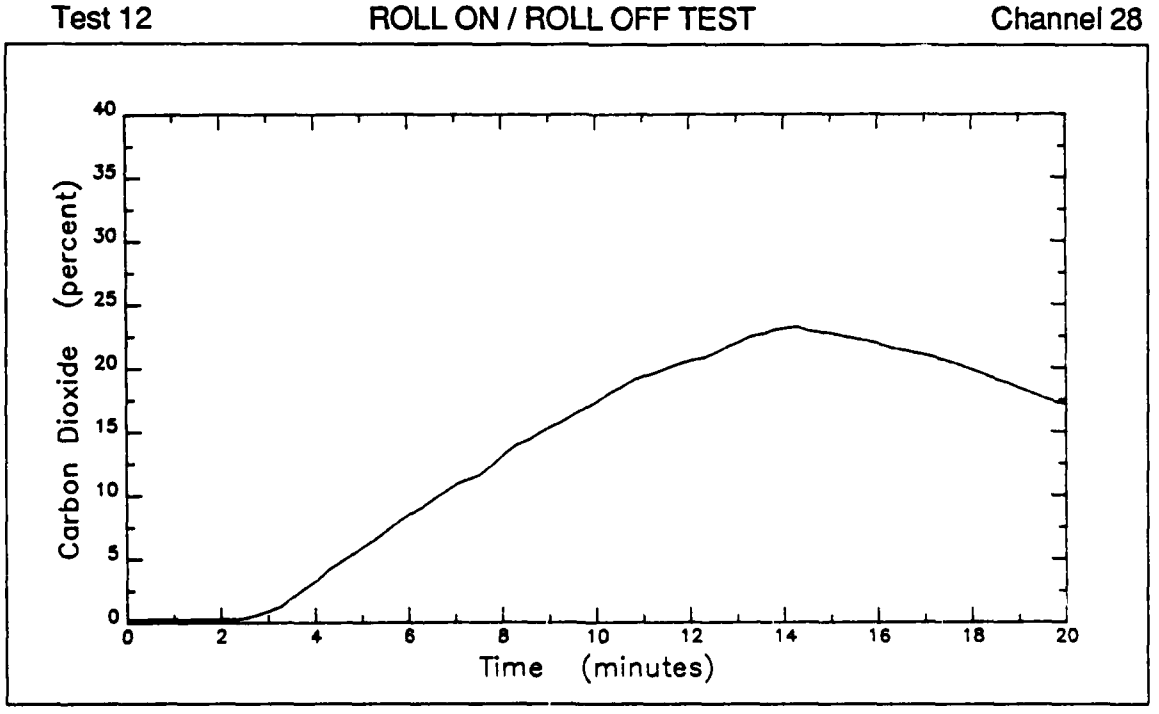



b. Test location - Automobile 10A

**FIGURE B 12-8. PERCENT CARBON DIOXIDE vs TIME**

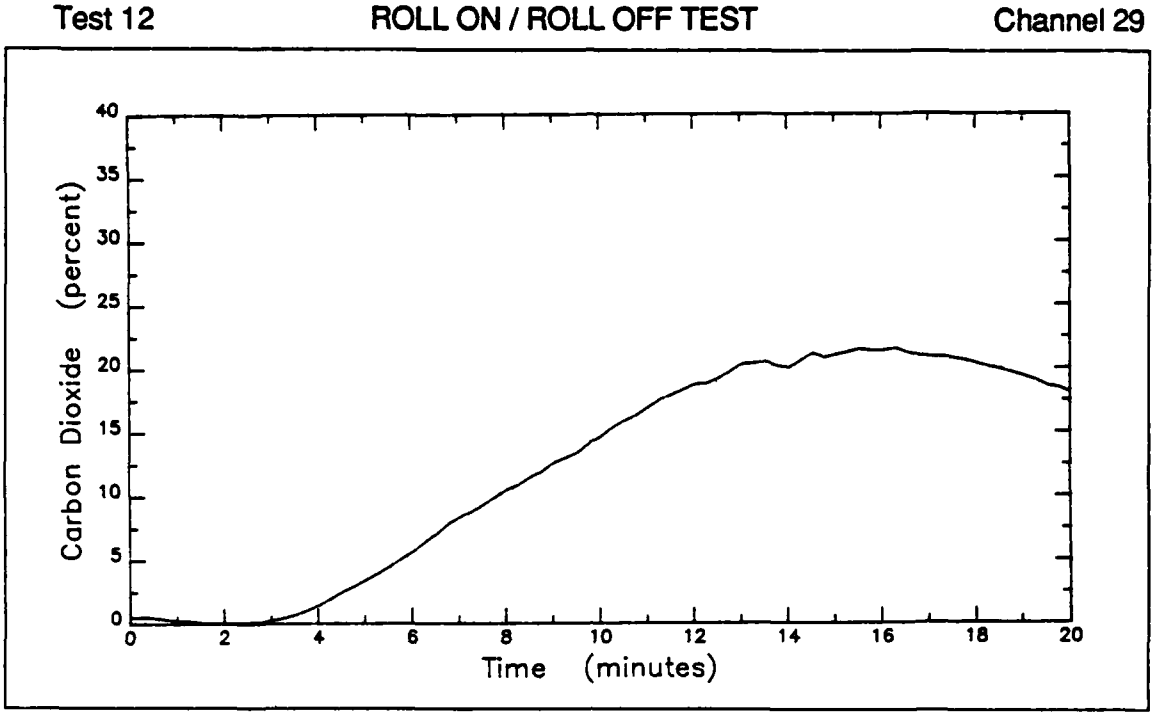



c. Test location - Automobile 11A

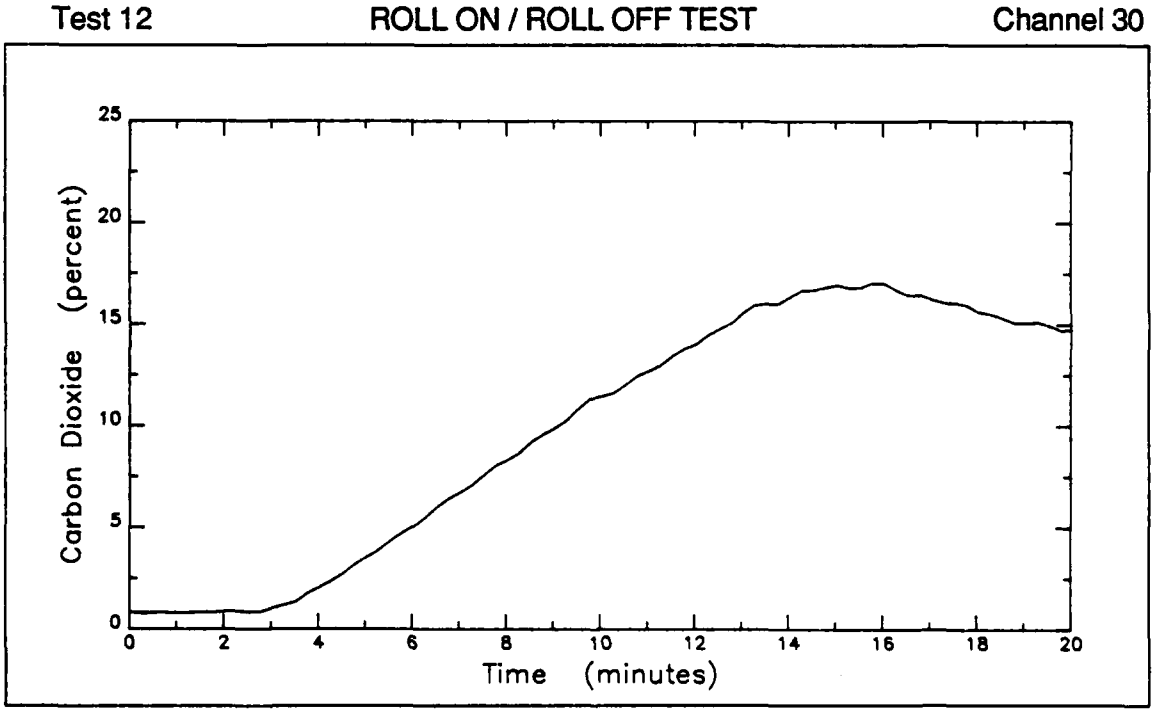



d. Test location - Automobile 12A

**FIGURE B 12-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

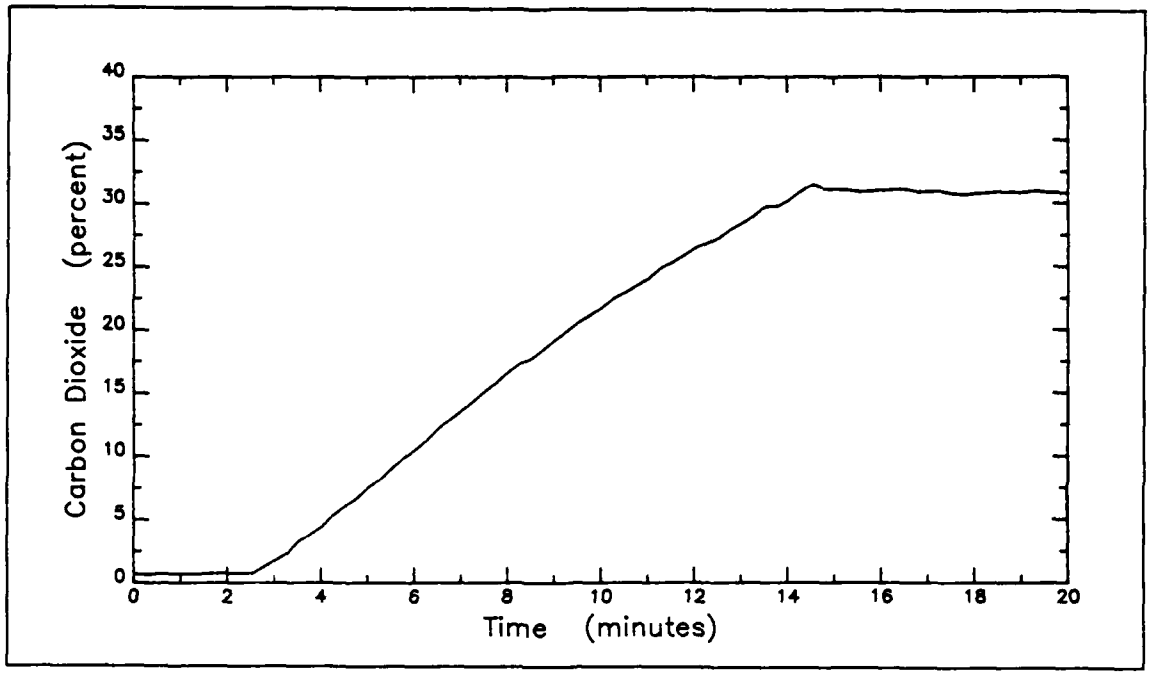



e. Test location - Automobile 9C

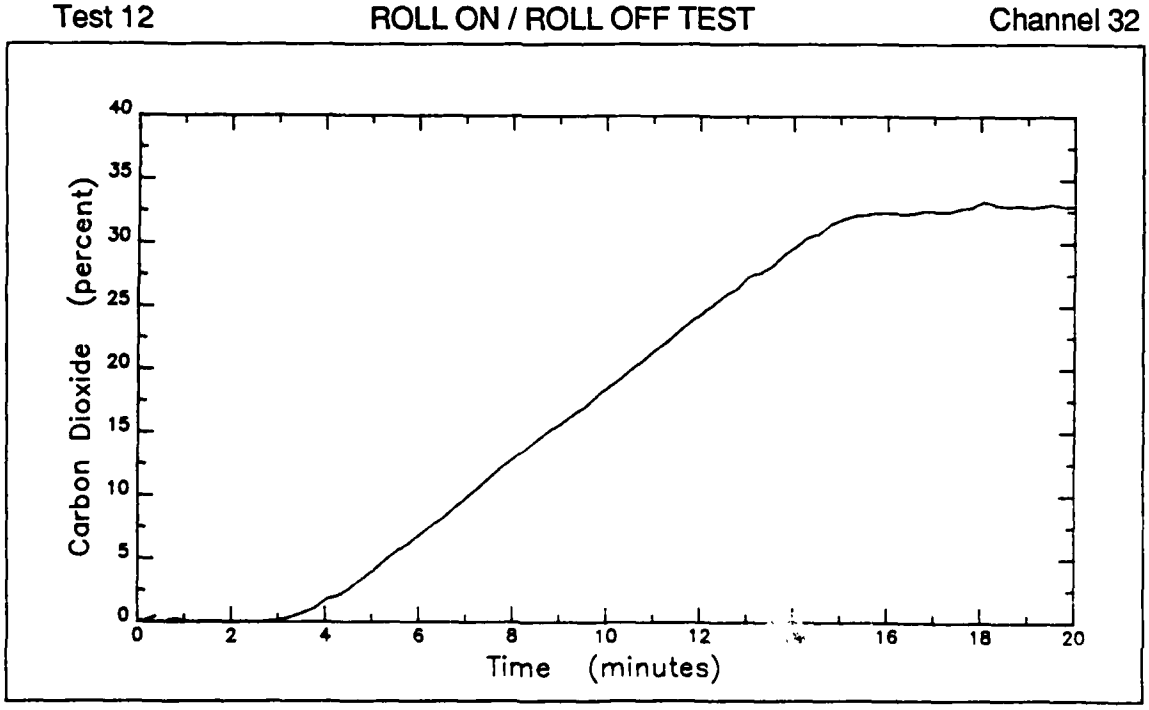



f. Test location - Automobile 3A

**FIGURE B 12-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

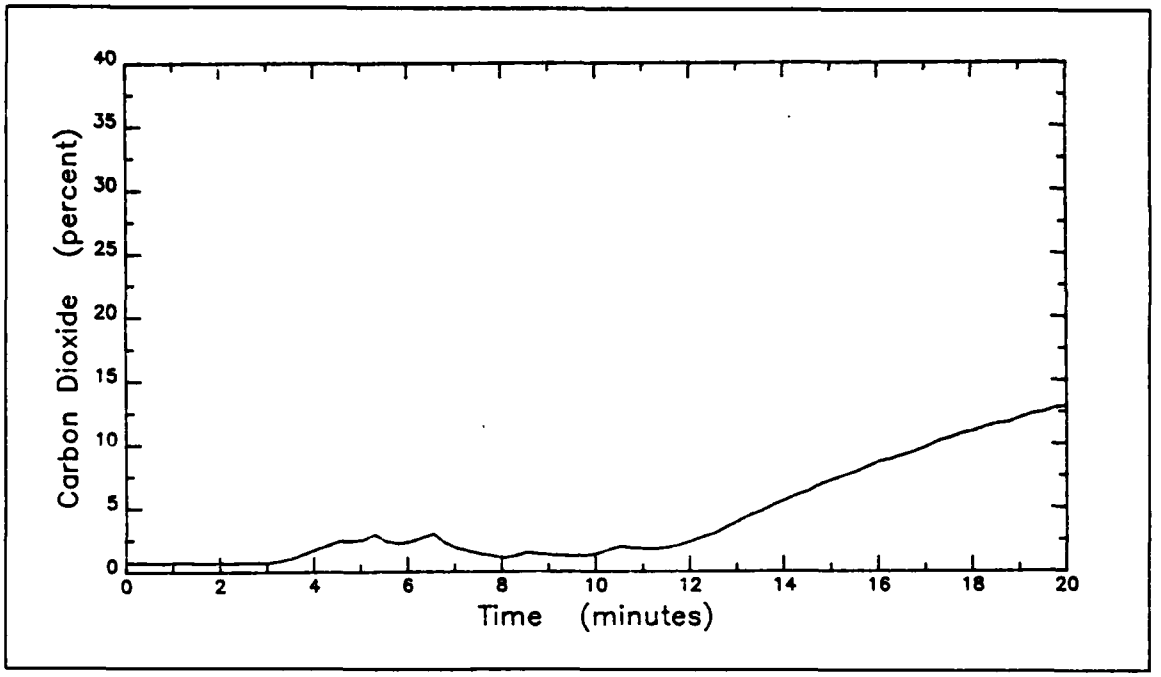



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 12-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

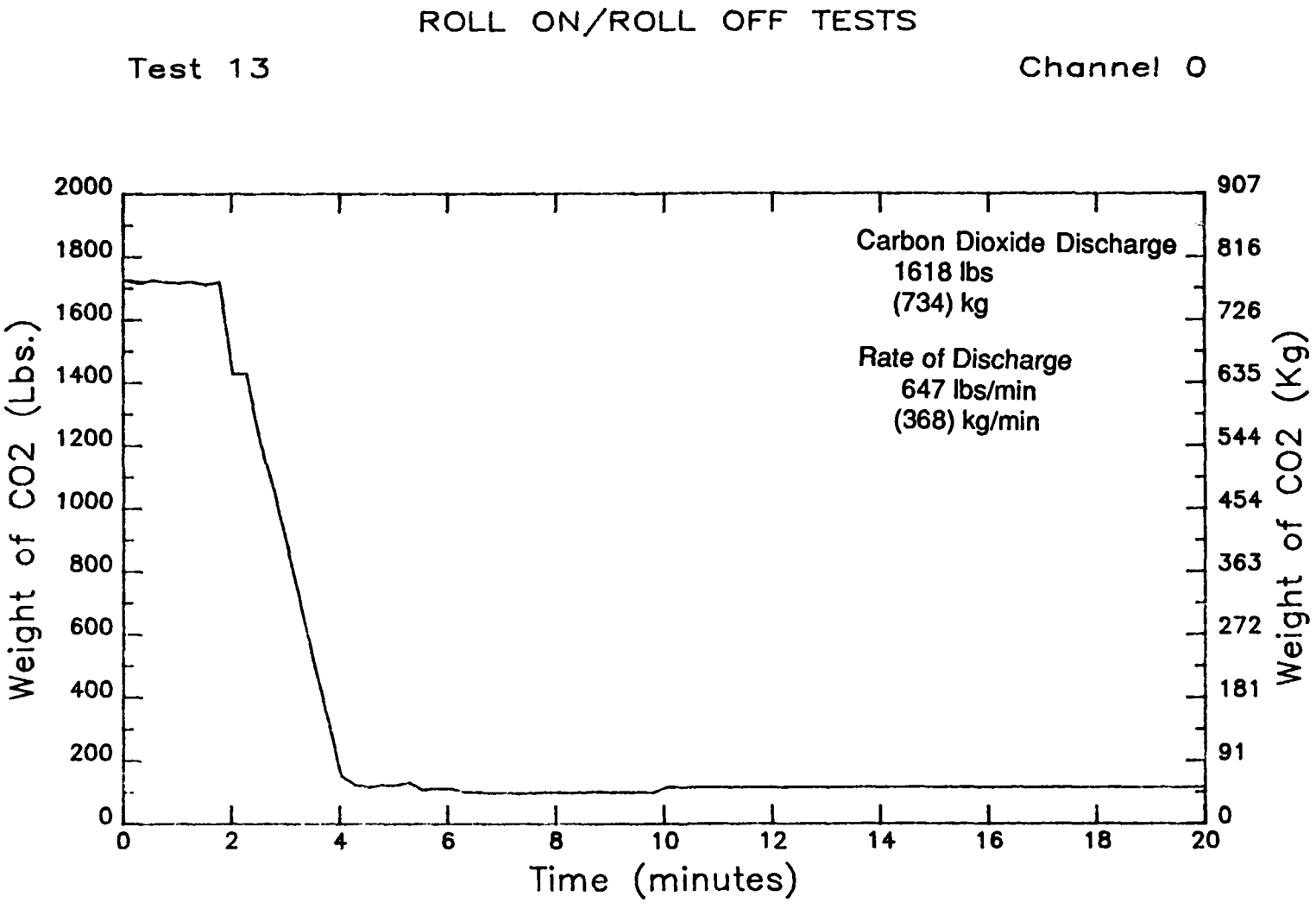



i. Test location - Automobile 3B

**FIGURE B 12-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

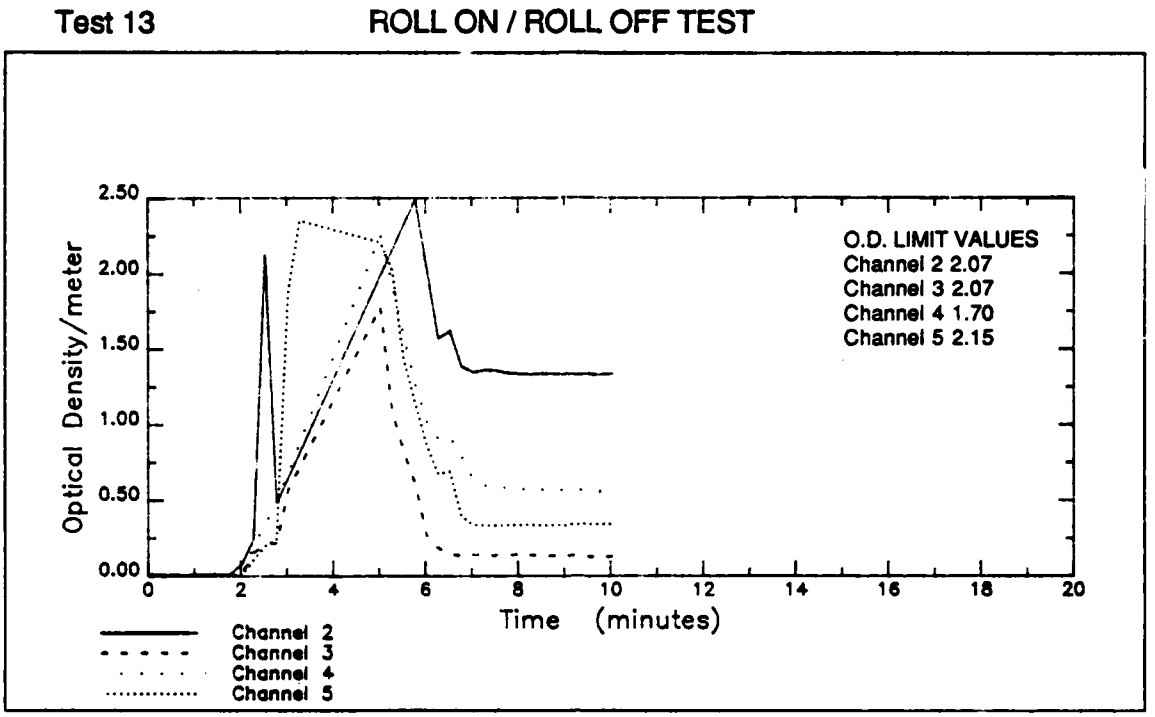
# APPENDIX B

# TEST 13

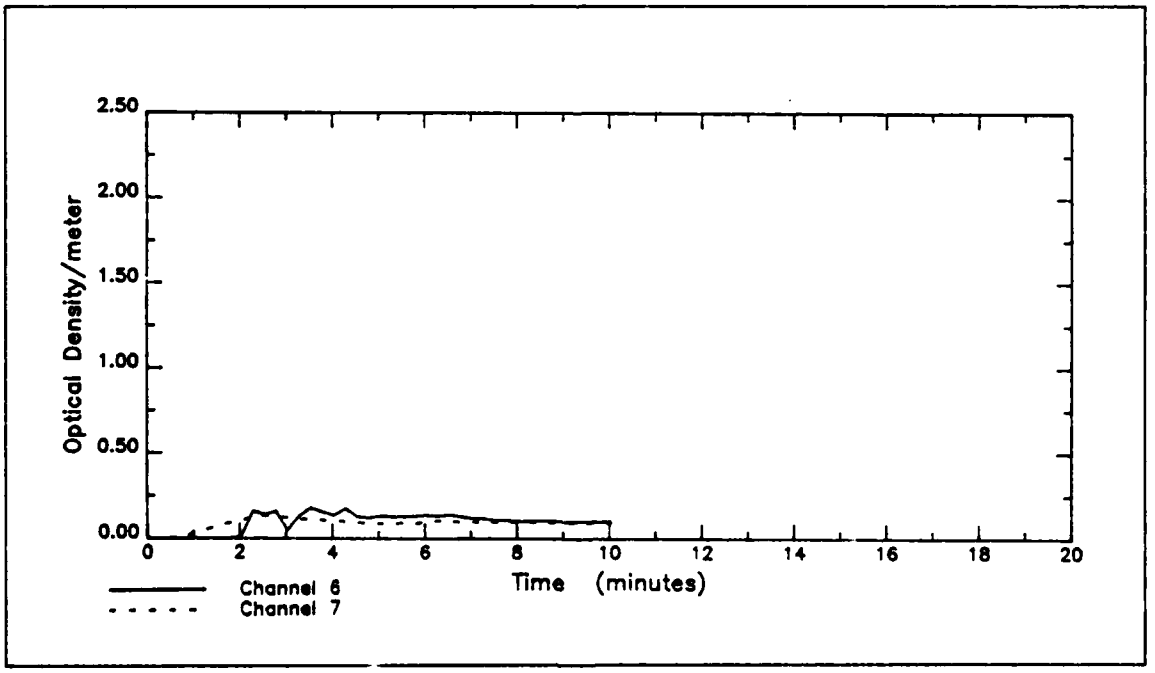



B 13-1

FIGURE B 13-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 13-2. OPTICAL DENSITY vs TIME**

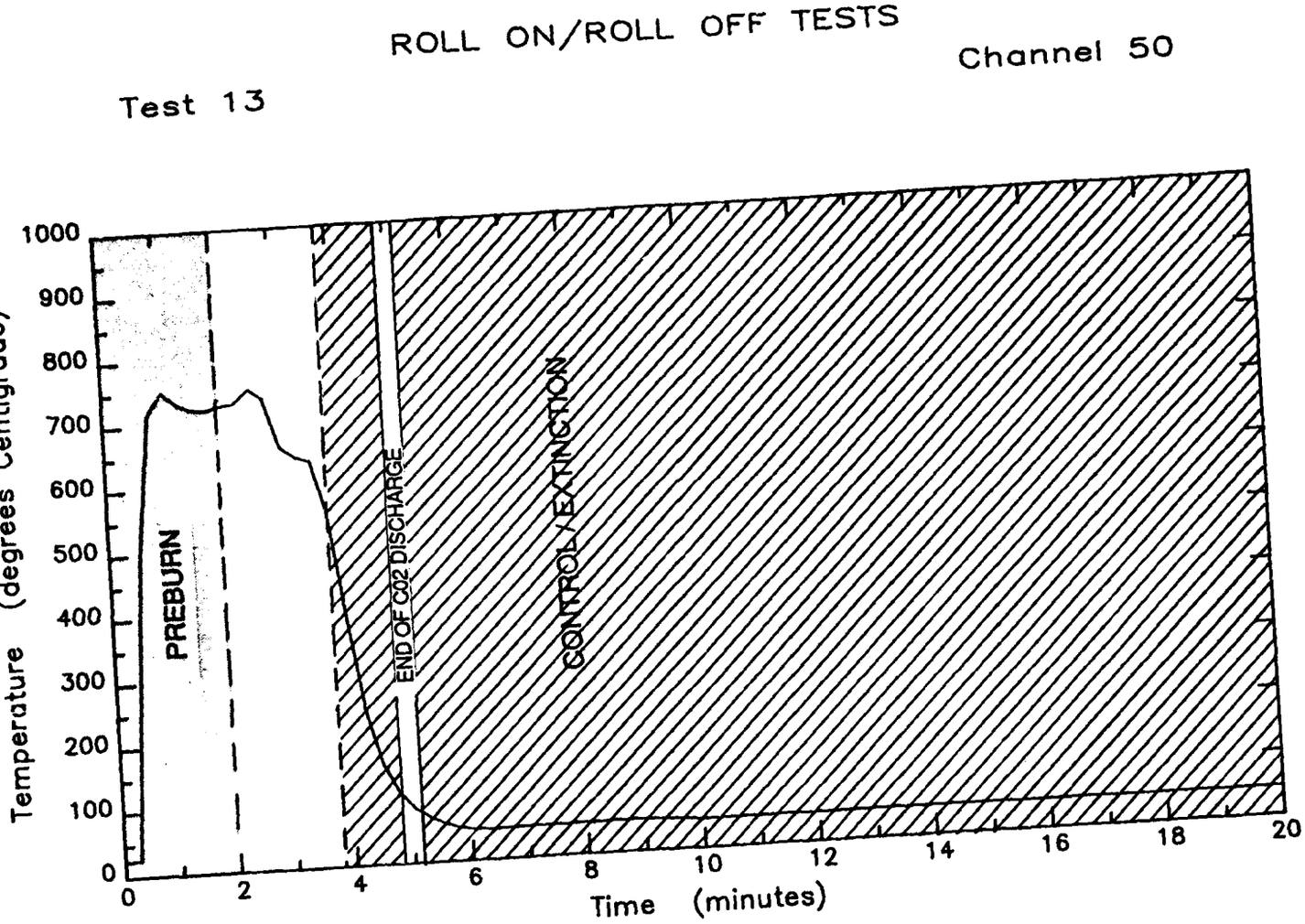
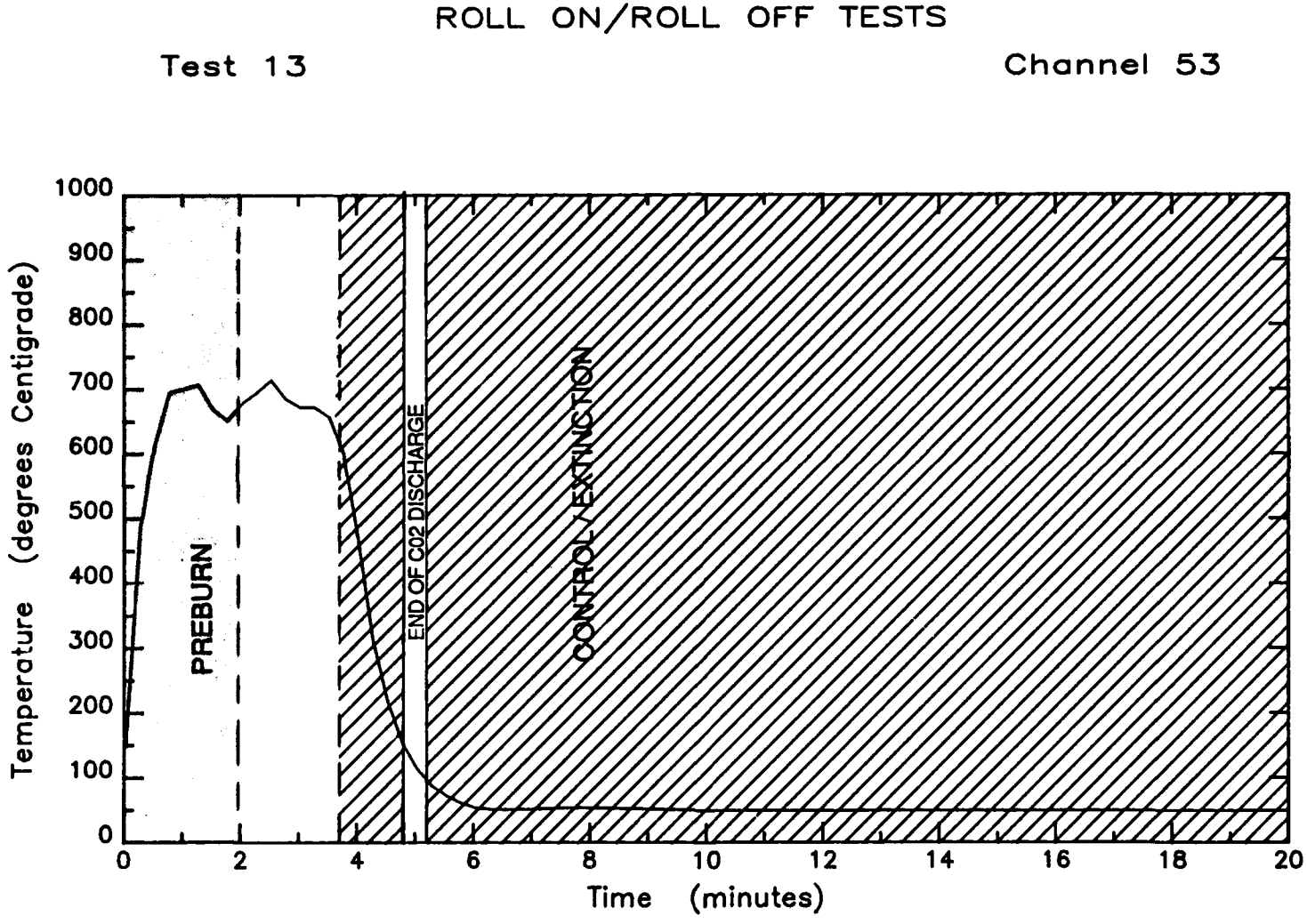



FIGURE B 13-3. Temperature vs Time - Location 9A




B 13-4

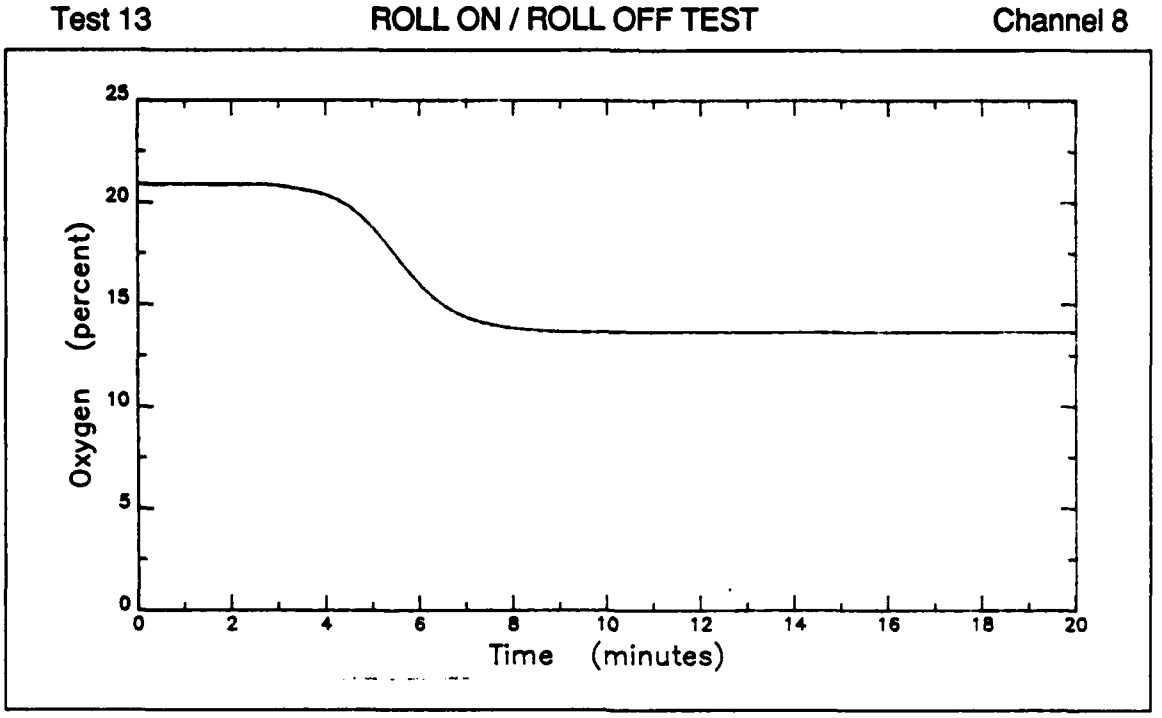
FIGURE B 13-4. Temperature vs Time - Location 10A

TEST 13

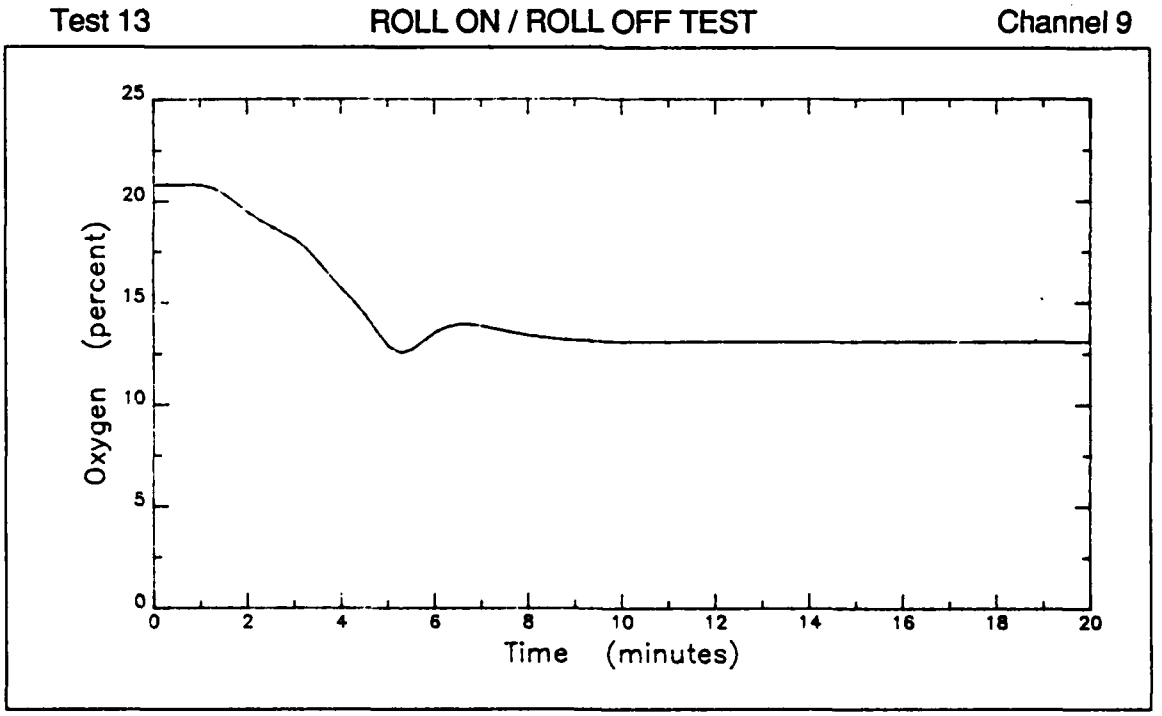
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 3.8 | 20.4 | 10.0 | 13.6 | 14.4% OXYGEN @ 6.8 MINUTES |
| 9 | Auto 10A | 3.8 | -- | -- | -- | |
| 10 | Auto 12A | 3.8 | 20.8 | 9.8 | 13.6 | 14.4% OXYGEN @ 7.4 MINUTES |
| 11 | Auto 11A | 3.8 | 18.8 | 8.3 | 14.8 | |
| 12 | Auto 9B | 3.8 | 17.9 | 7.0 | 14.7 | |
| 13 | Auto 12B | 3.8 | 20.0 | 10.0 | 16.3 | |
| | | AVERAGE | 19.6 | 8.4 | 14.4 | |



FIGURE B 13-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

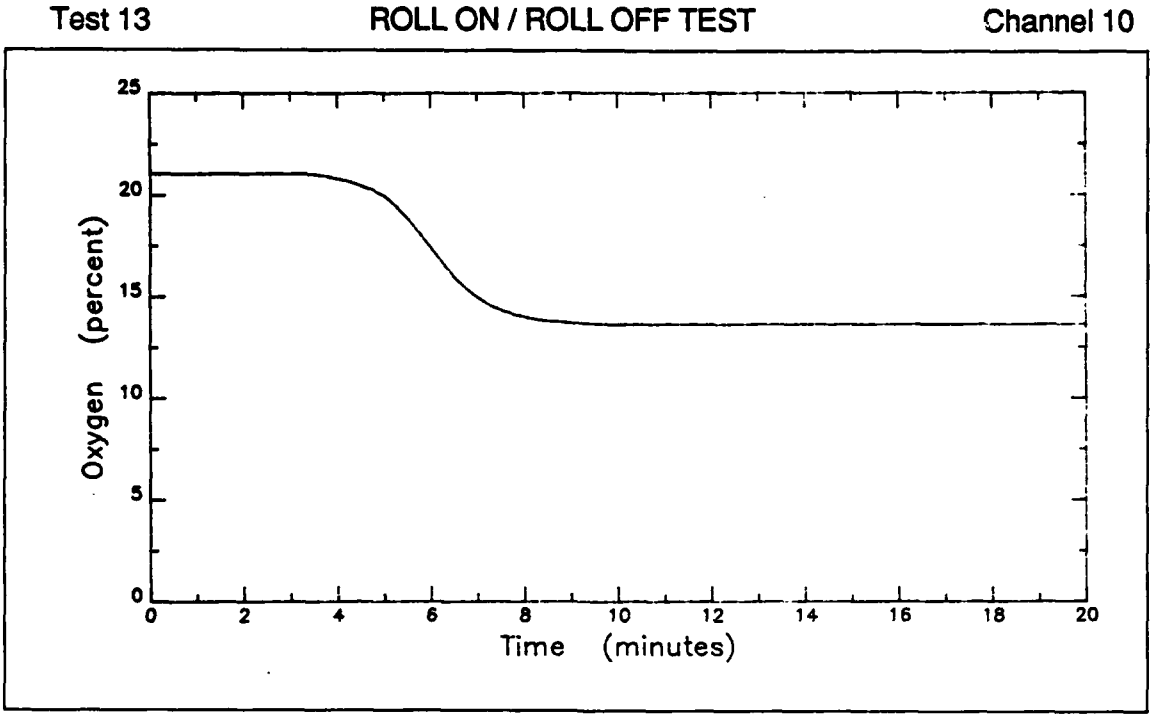



a. Test location - Automobile 9A

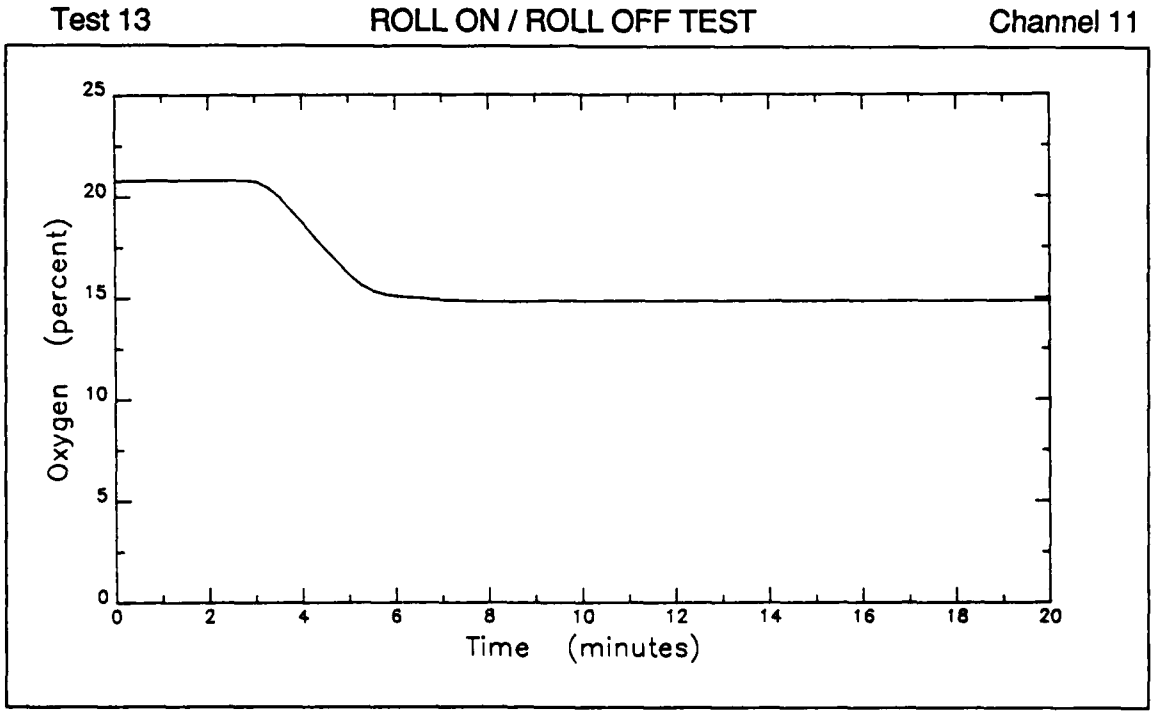



b. Test location - Automobile 10A

**FIGURE B 13-6. PERCENT OXYGEN vs TIME**

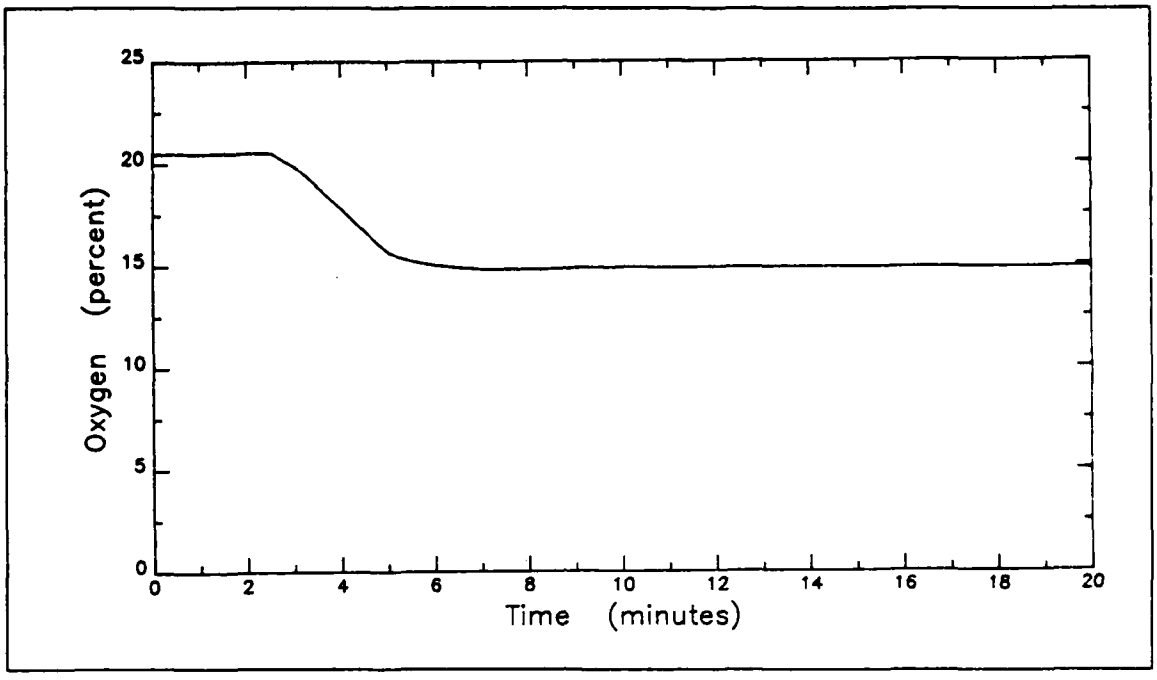



c. Test location - Automobile 11A

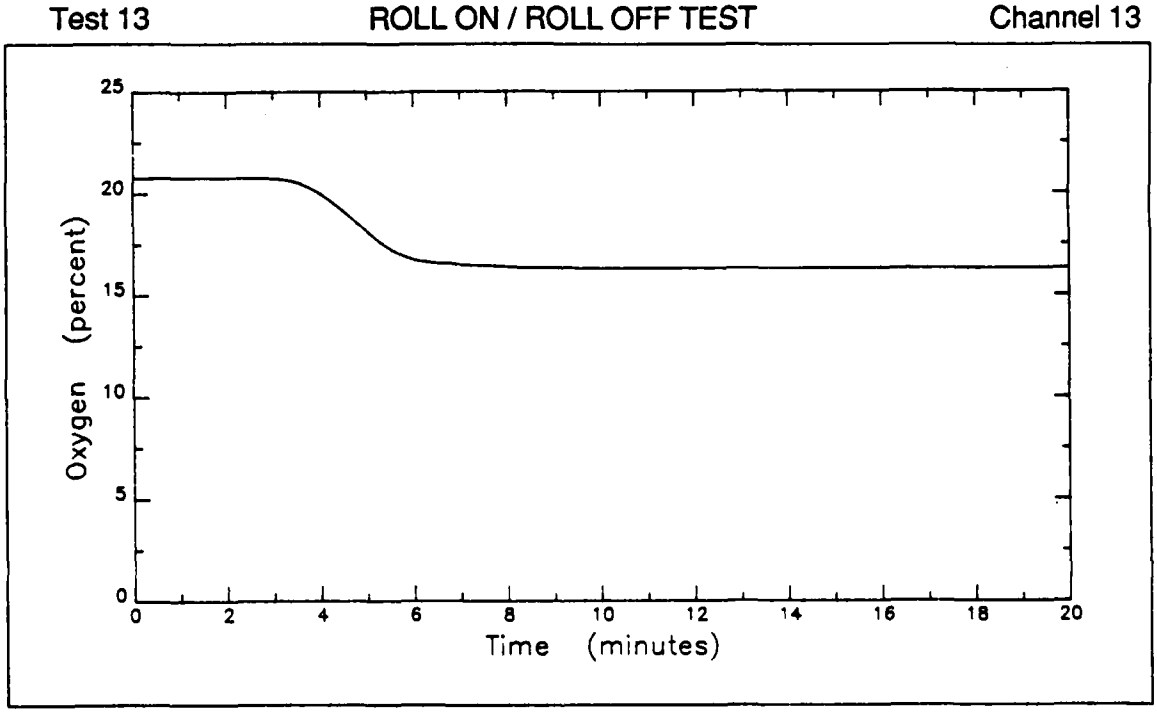



d. Test location - Automobile 12A

**FIGURE B 13-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B




f. Test location - Automobile 12B

**FIGURE B 13-6. PERCENT OXYGEN vs TIME (cont'd)**

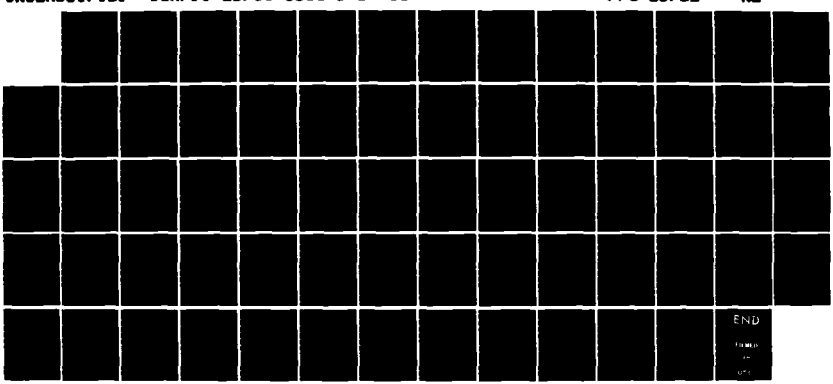
TEST 13

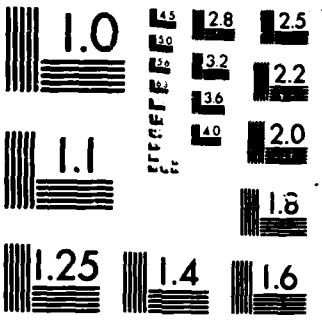
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 3.8 | 16.3 | 6.3 | 26.5 | |
| 26 | Auto 10A | 3.8 | 25.0 | 5.0 | 31.1 | |
| 27 | Auto 11A | 3.8 | 15.0 | 7.5 | 35.8 | |
| 28 | Auto 12A | 3.8 | 17.5 | 6.0 | 31.8 | |
| 29 | Auto 9C | 3.8 | 10.2 | 6.5 | 28.2 | |
| 30 | Auto 3A | 3.8 | 8.7 | 6.5 | 29.0 | |
| 31 | Auto 9B | 3.8 | 18.6 | 7.3 | 38.7 | |
| 32 | Auto 12B | 3.8 | 8.2 | 9.5 | 39.2 | |
| 33 | Auto 3B | 3.8 | 12.4 | 6.5 | 33.4 | |
| | | AVERAGE | 14.7 | 6.7 | 32.6 | |

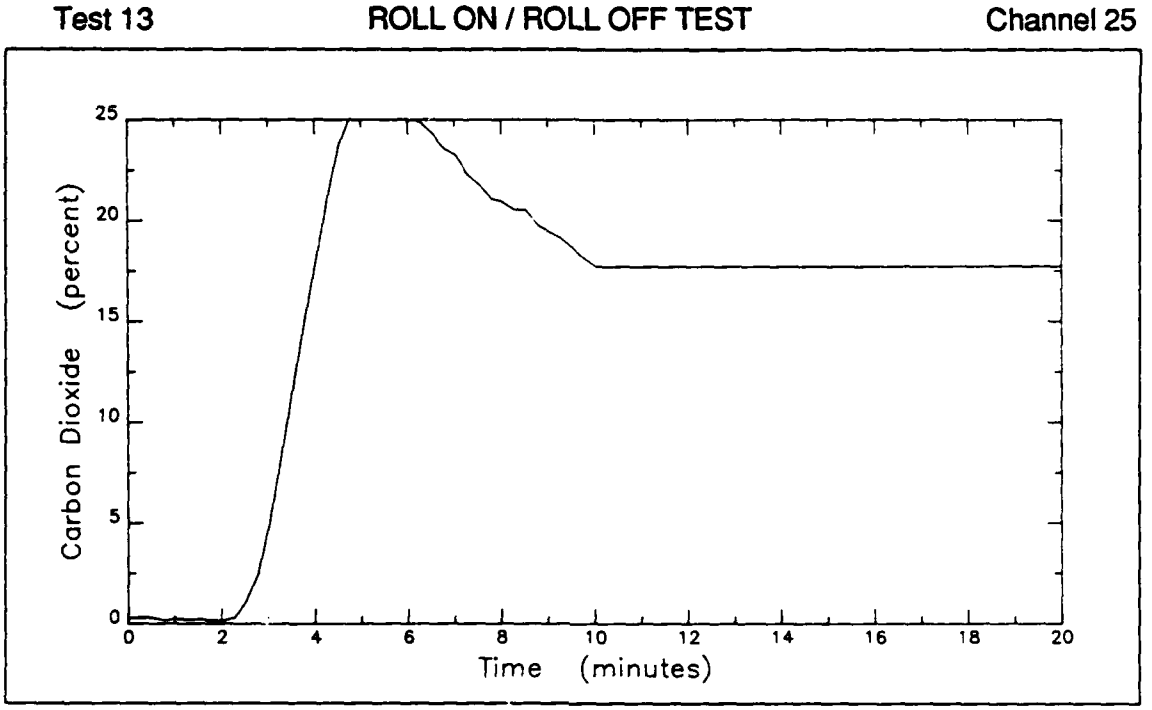
FIGURE B 13-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

AD-A163 185 ROLL-ON/ROLL-OFF AUTOMOBILE TRANSPORT SHIPS - AN ASSESSMENT OF CARBON DIO..(U) COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CT W H MCLAIN OCT 85 3/3

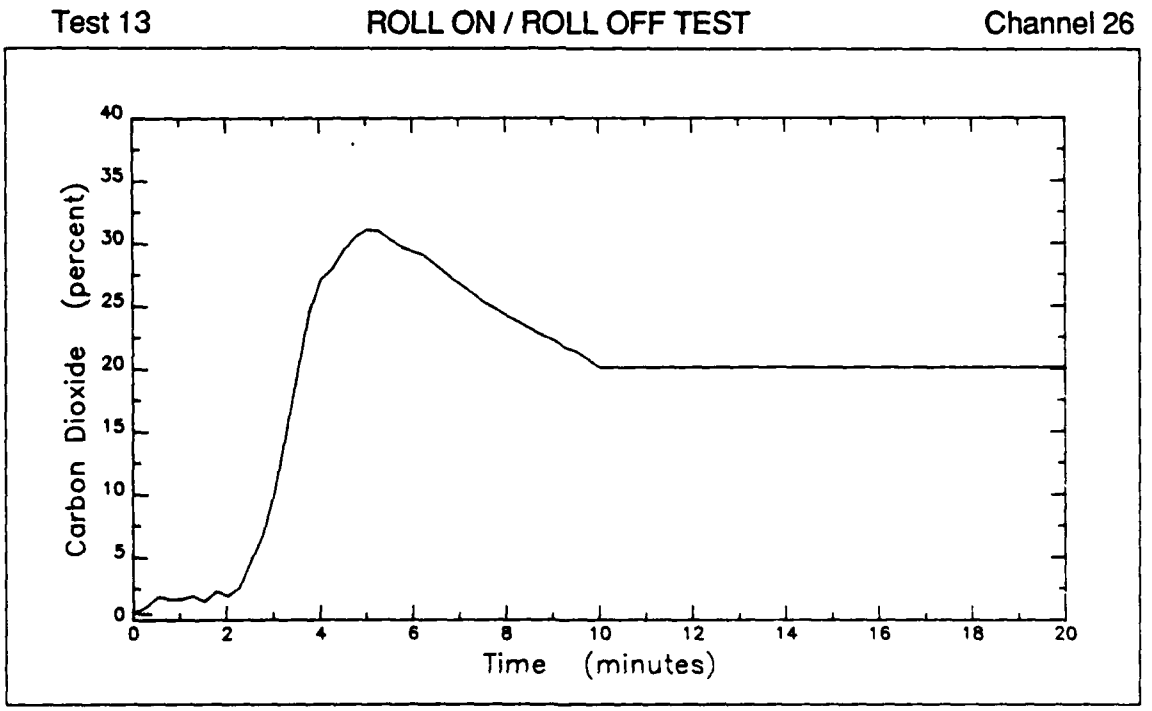
UNCLASSIFIED CGR/DC-13/85 USCG-D-34-85 F/G 13/12 NL





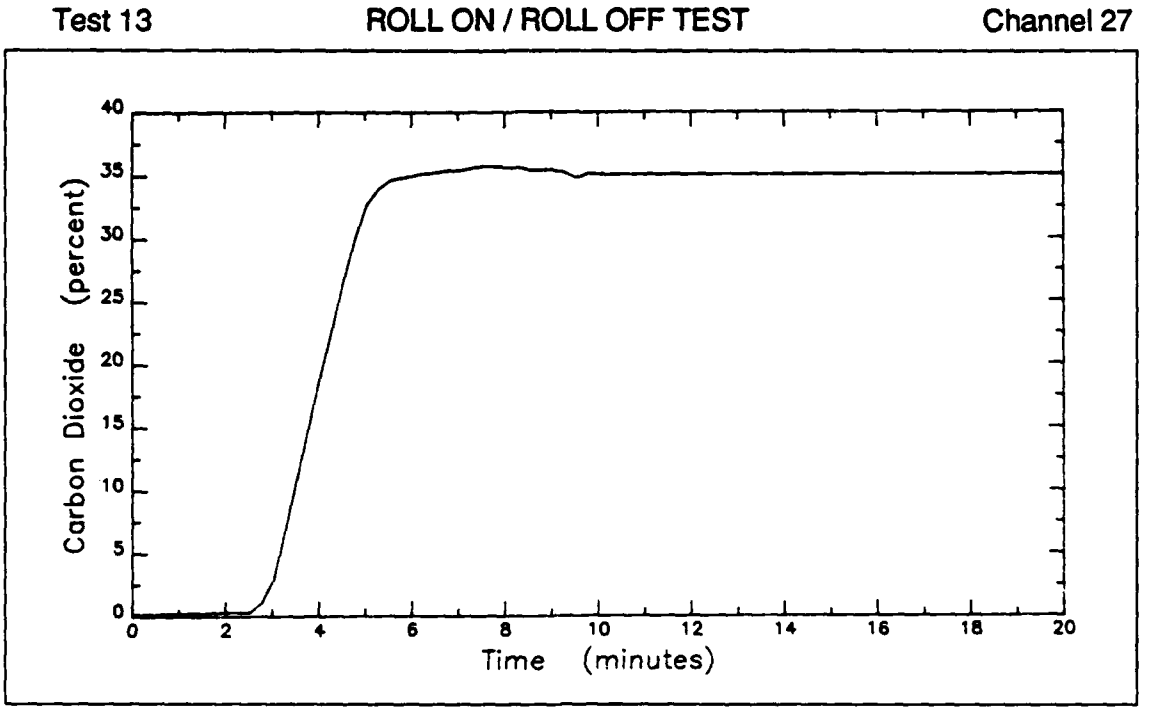



a. Test location - Automobile 9A

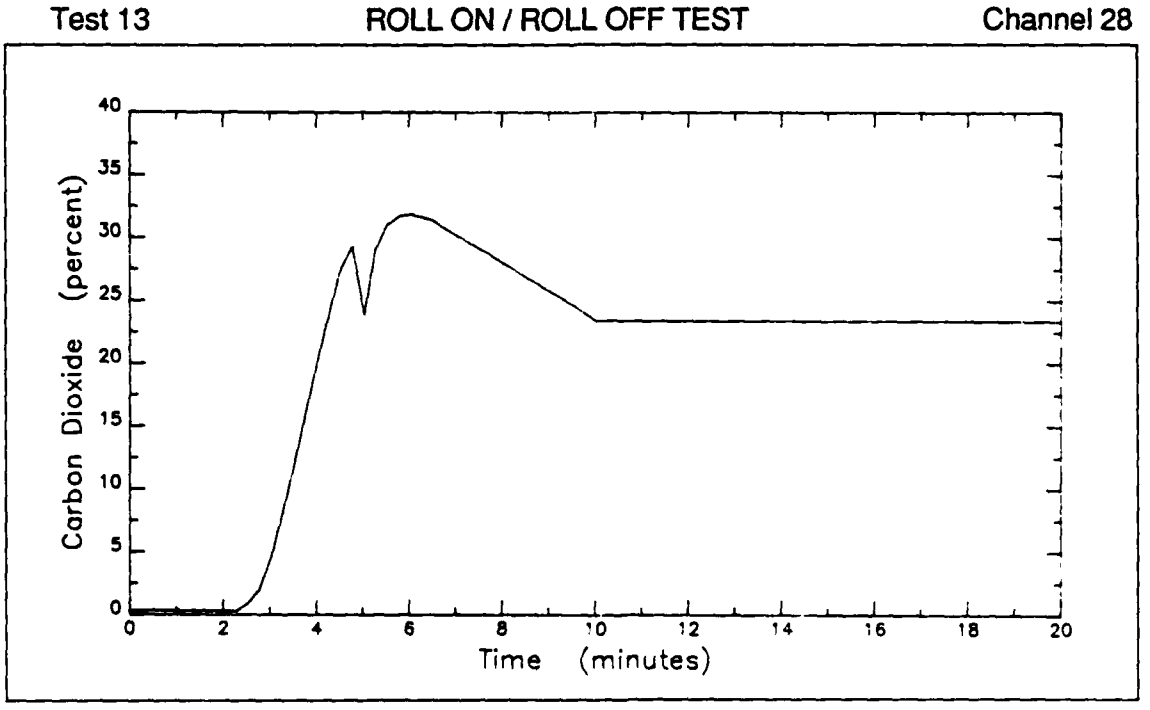



b. Test location - Automobile 10A

**FIGURE B 13-8. PERCENT CARBON DIOXIDE vs TIME**

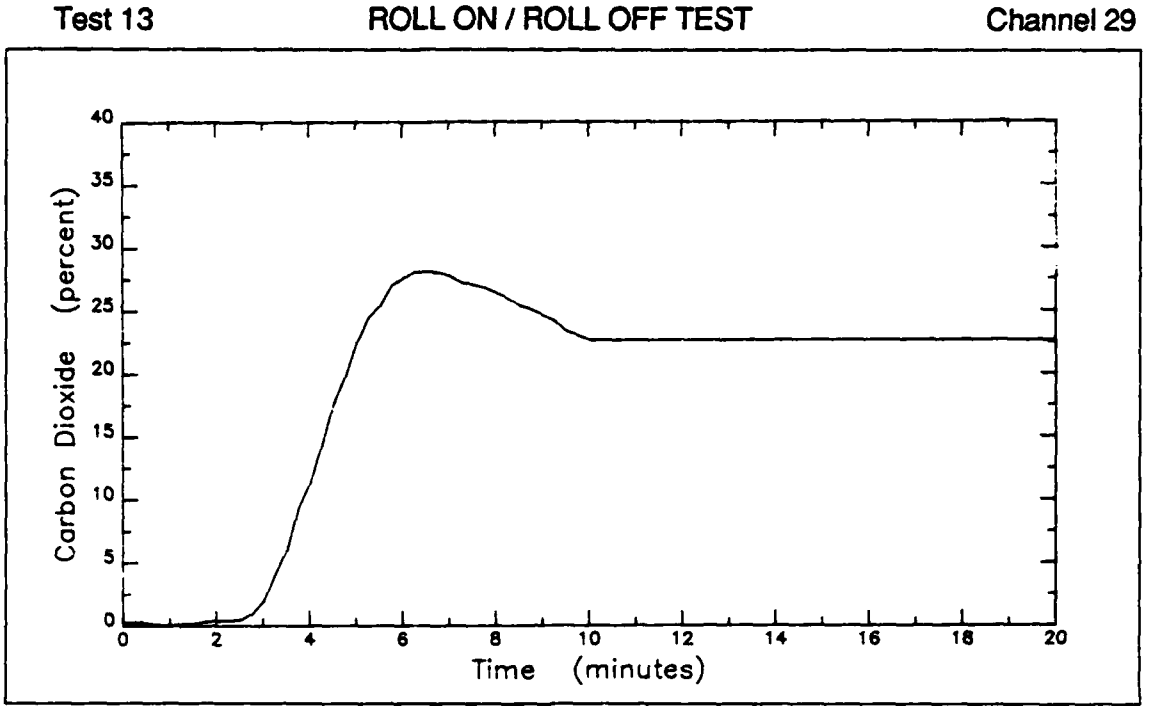



c. Test location - Automobile 11A

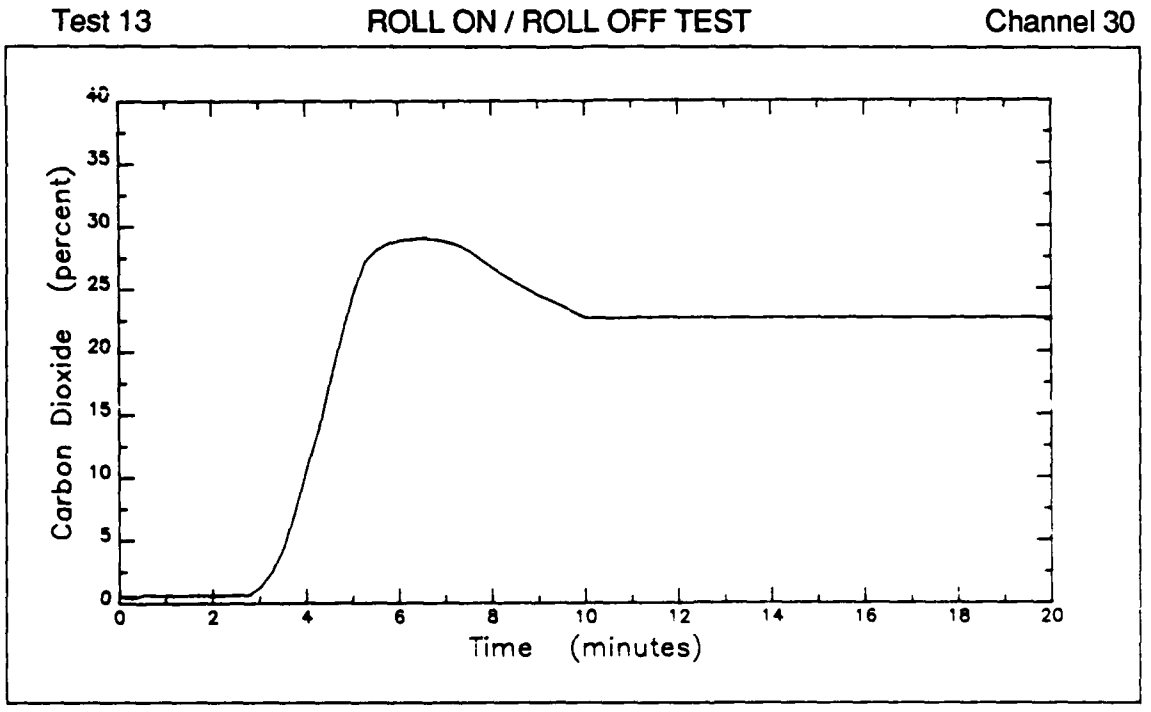



d. Test location - Automobile 12A

**FIGURE B 13-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

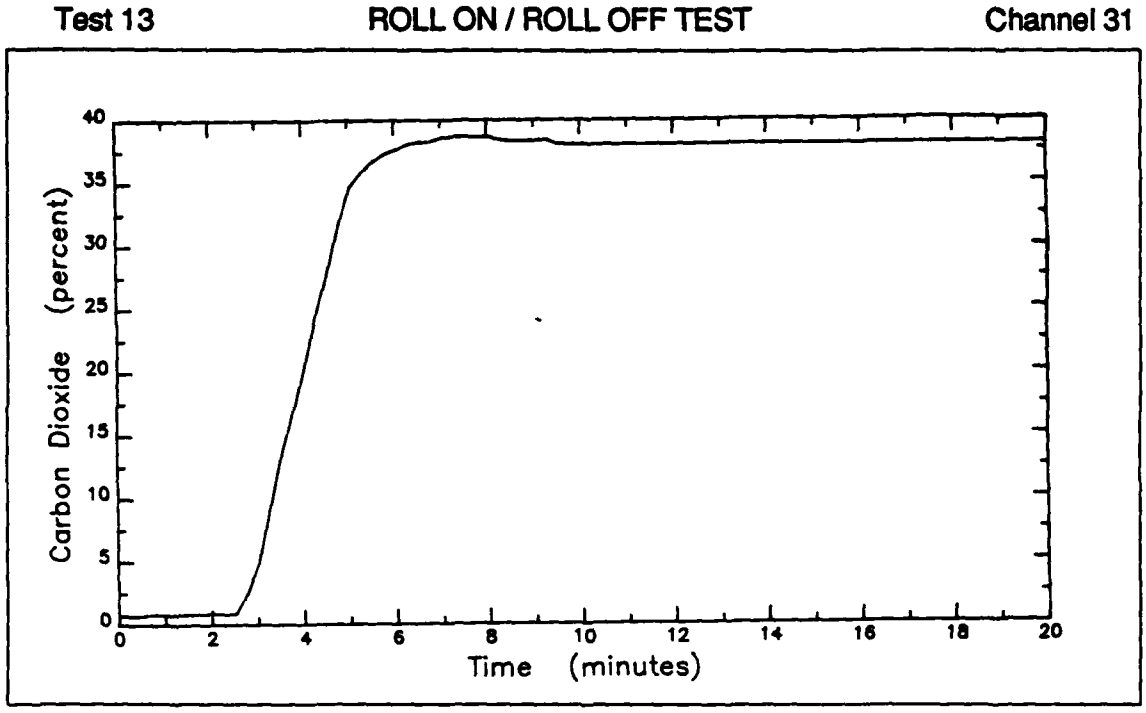



e. Test location - Automobile 9C

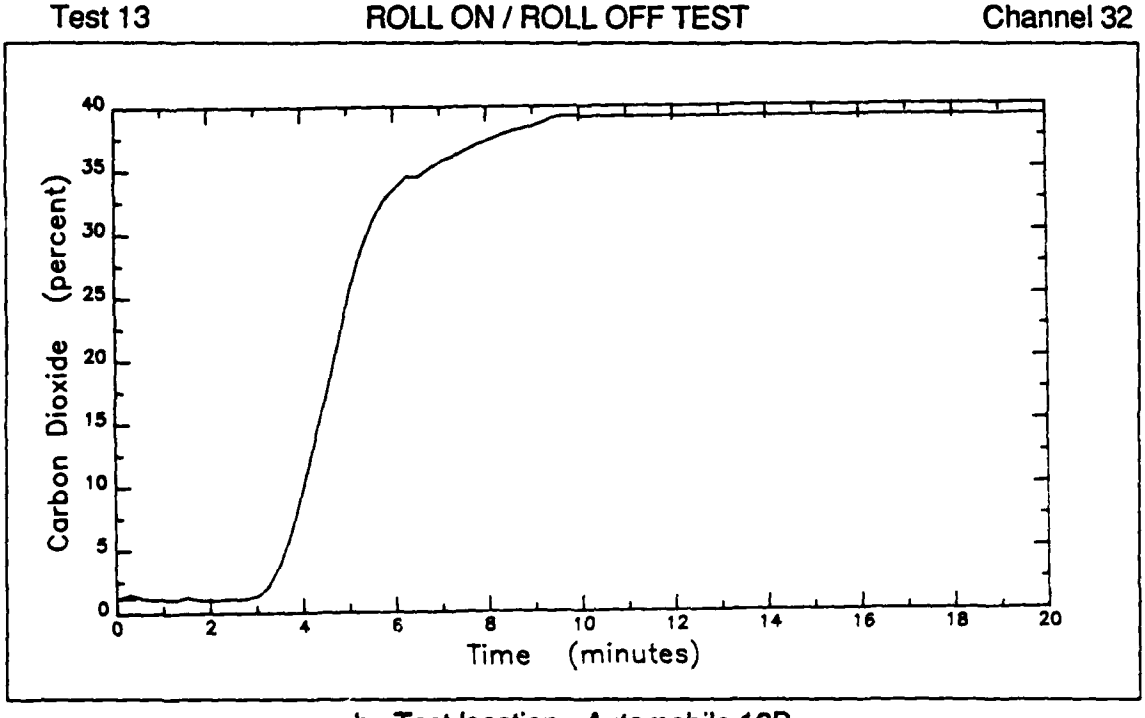



f. Test location - Automobile 3A

**FIGURE B 13-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

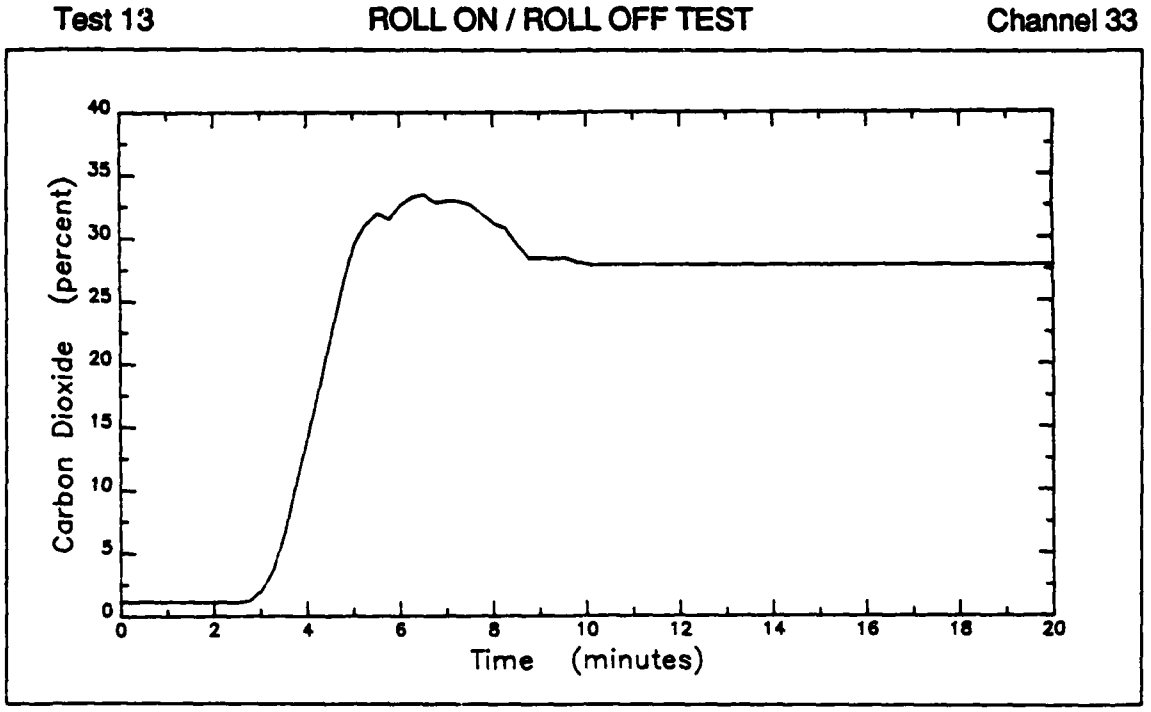



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 13-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 13-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

# TEST 14

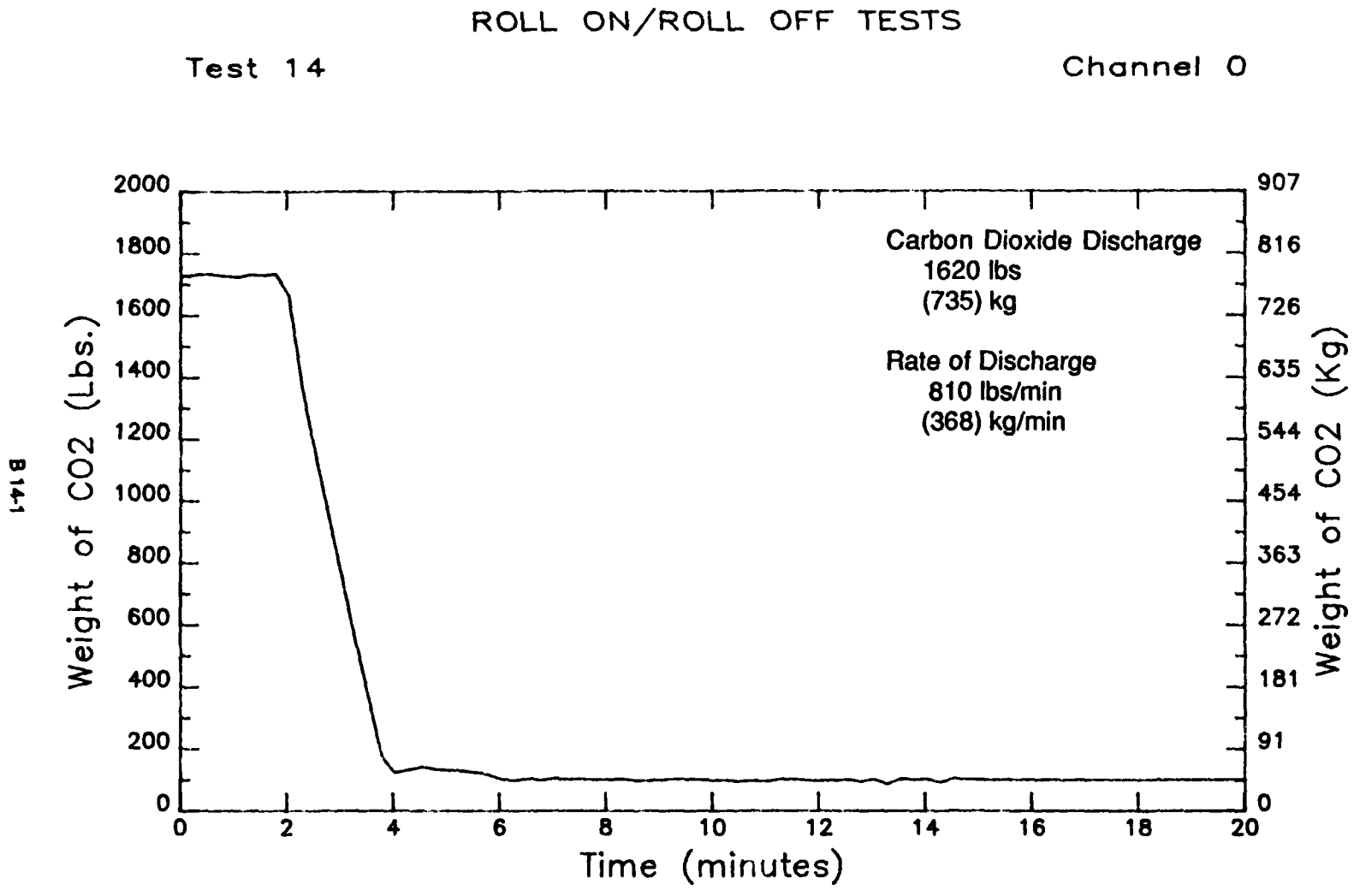
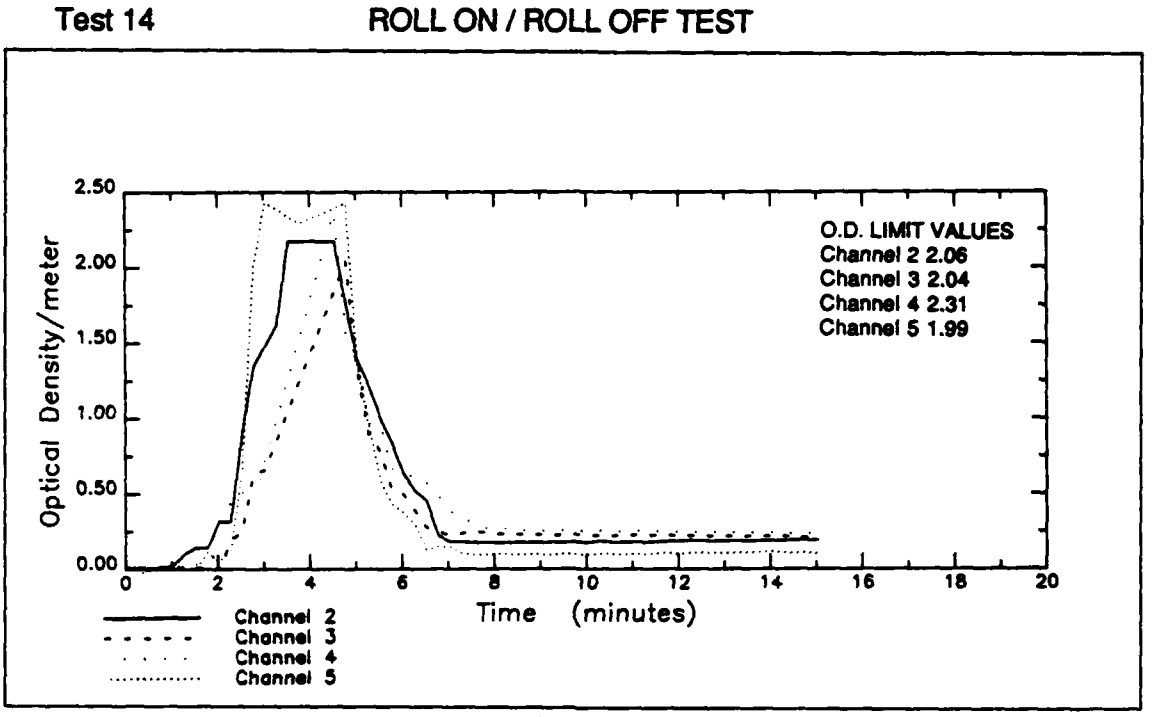
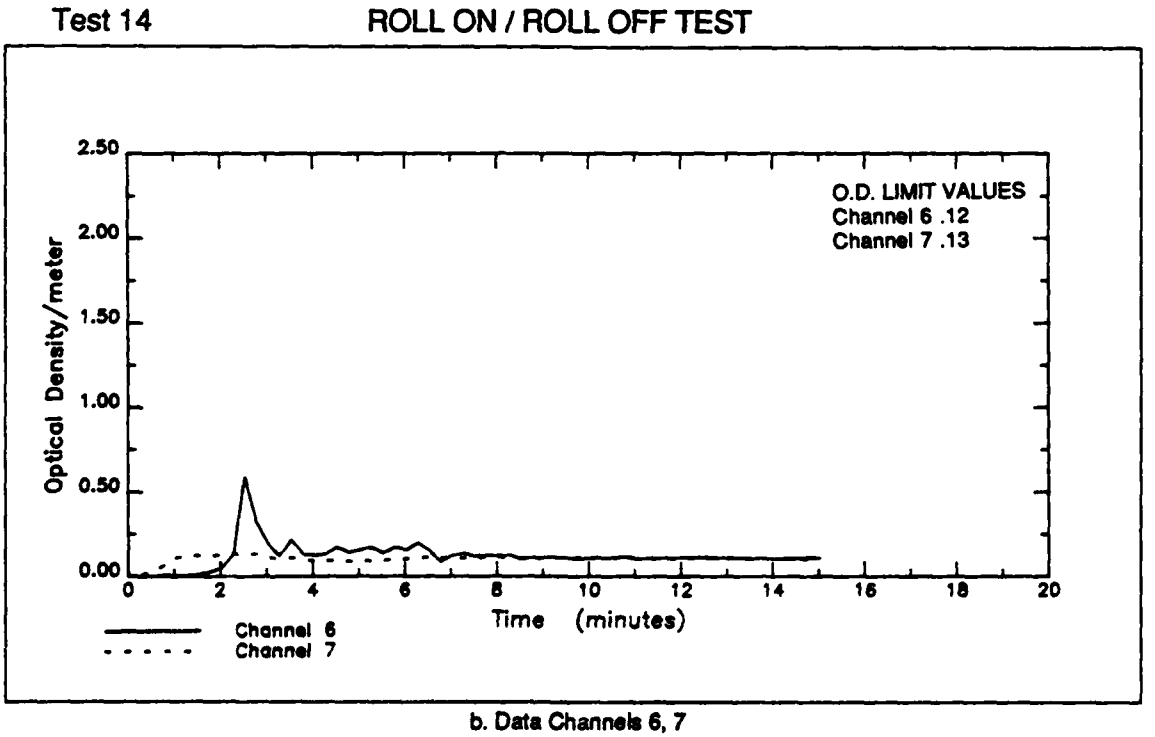



**FIGURE B 14-1. Weight of Carbon Dioxide vs Time**




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 14-2. OPTICAL DENSITY vs TIME**

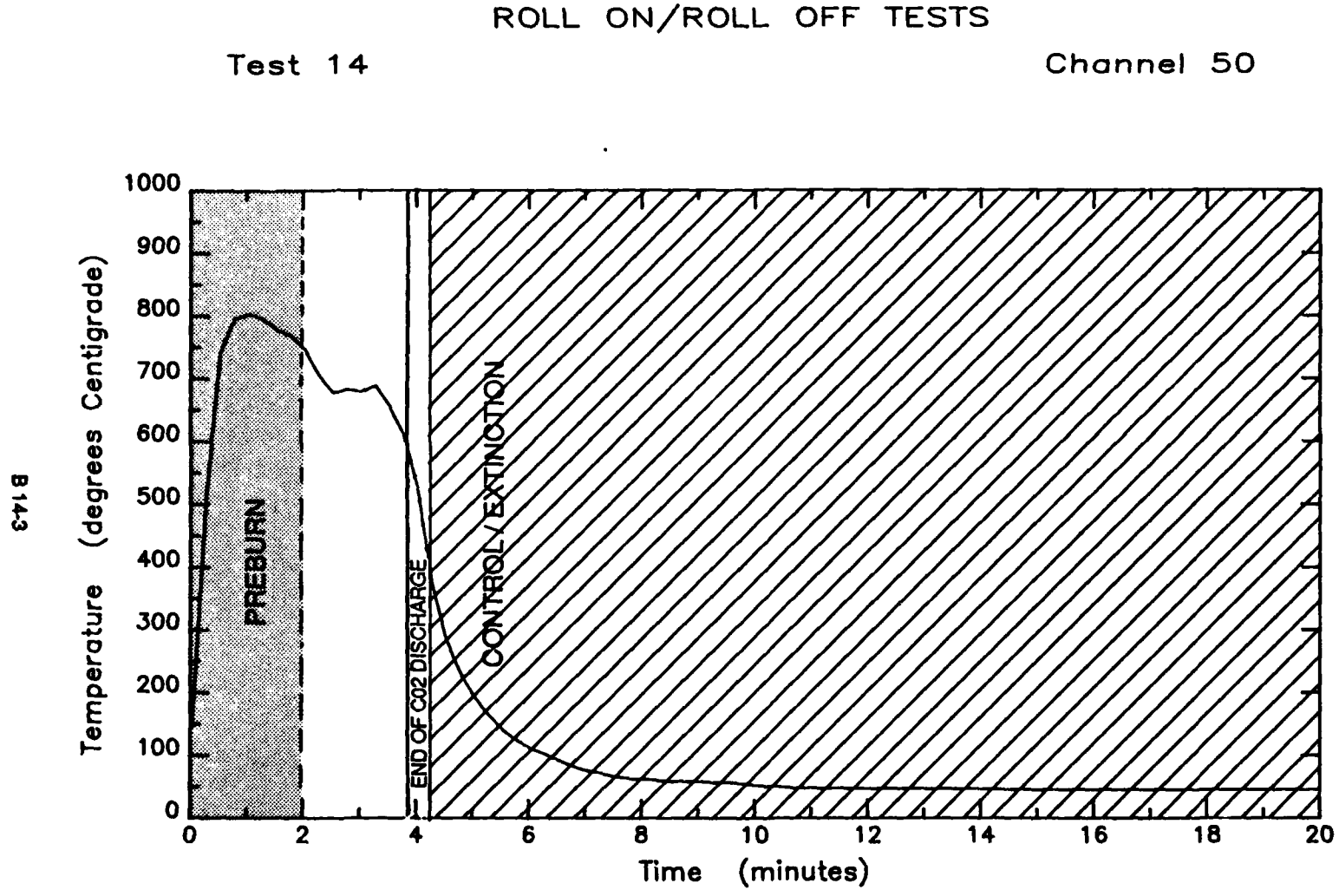
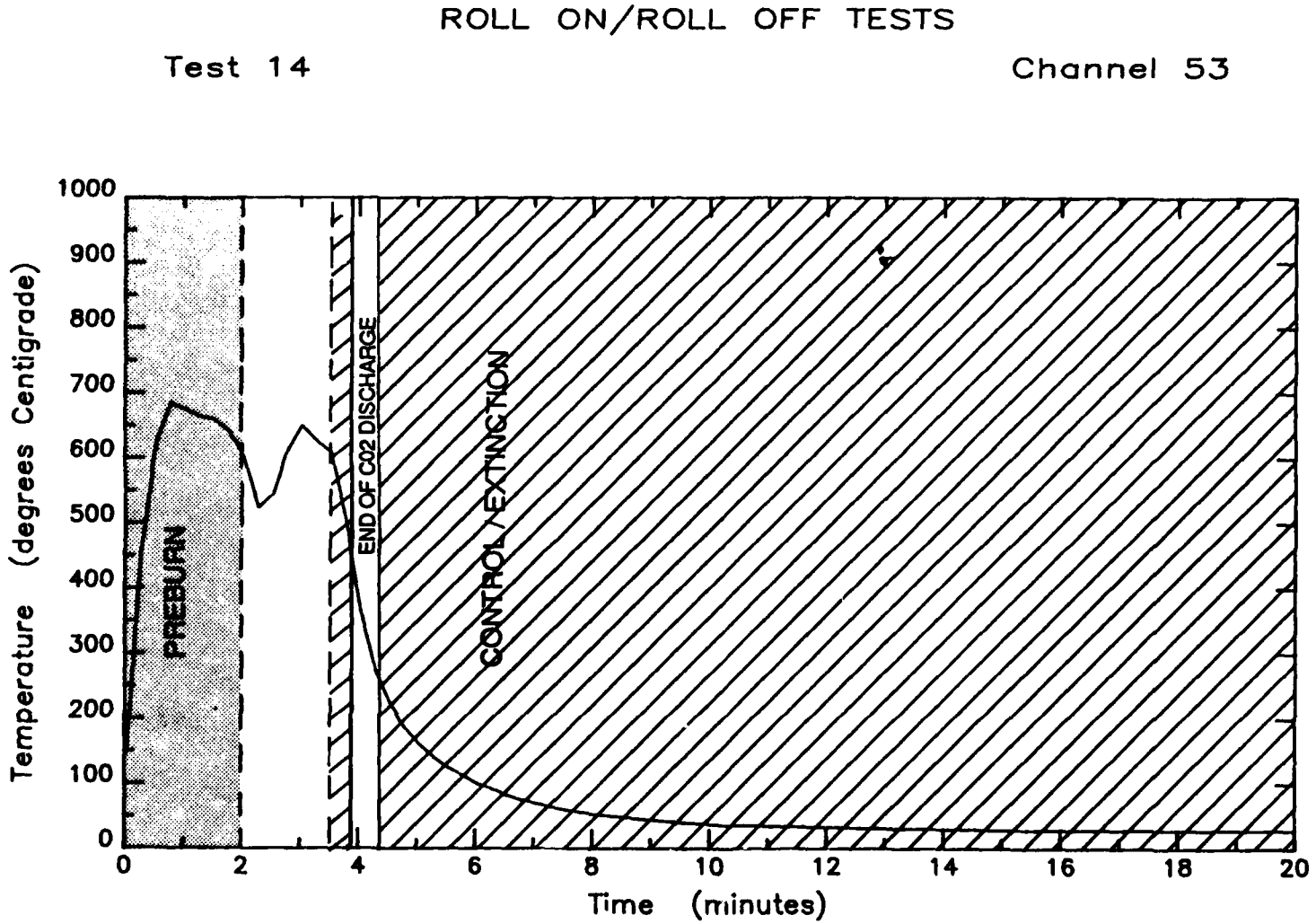



FIGURE B 14-3. Temperature vs Time - Location 9A



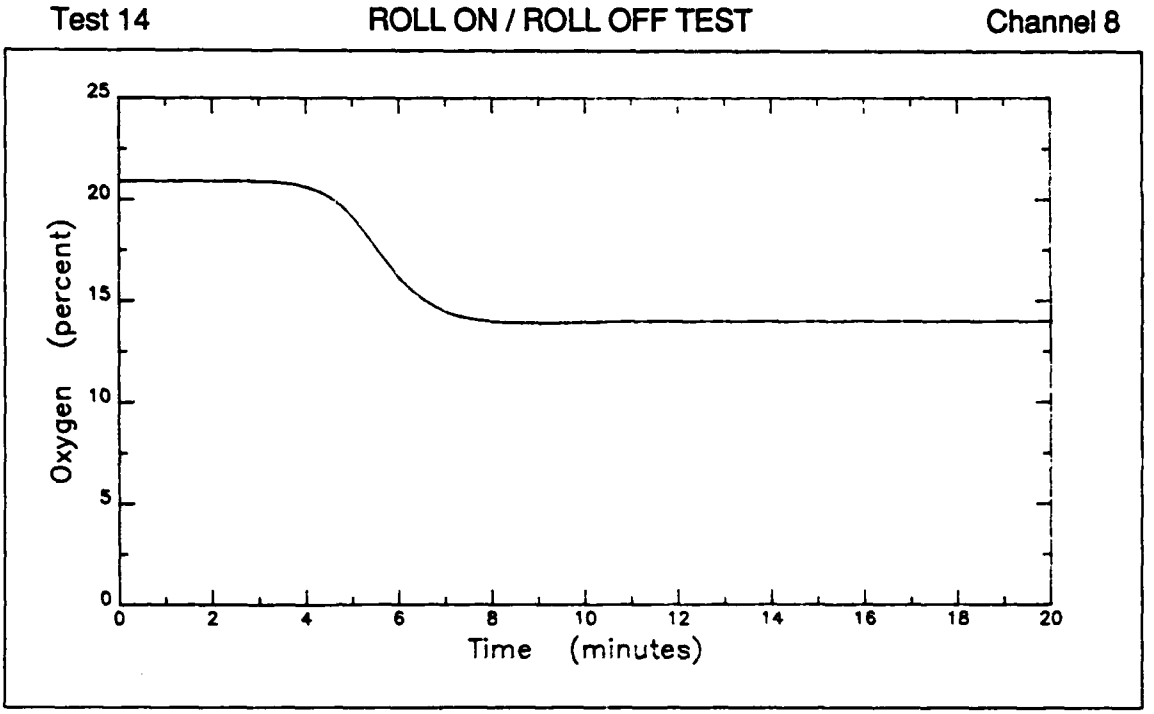

B 14-4

FIGURE B 14-4. Temperature vs Time - Location 10A

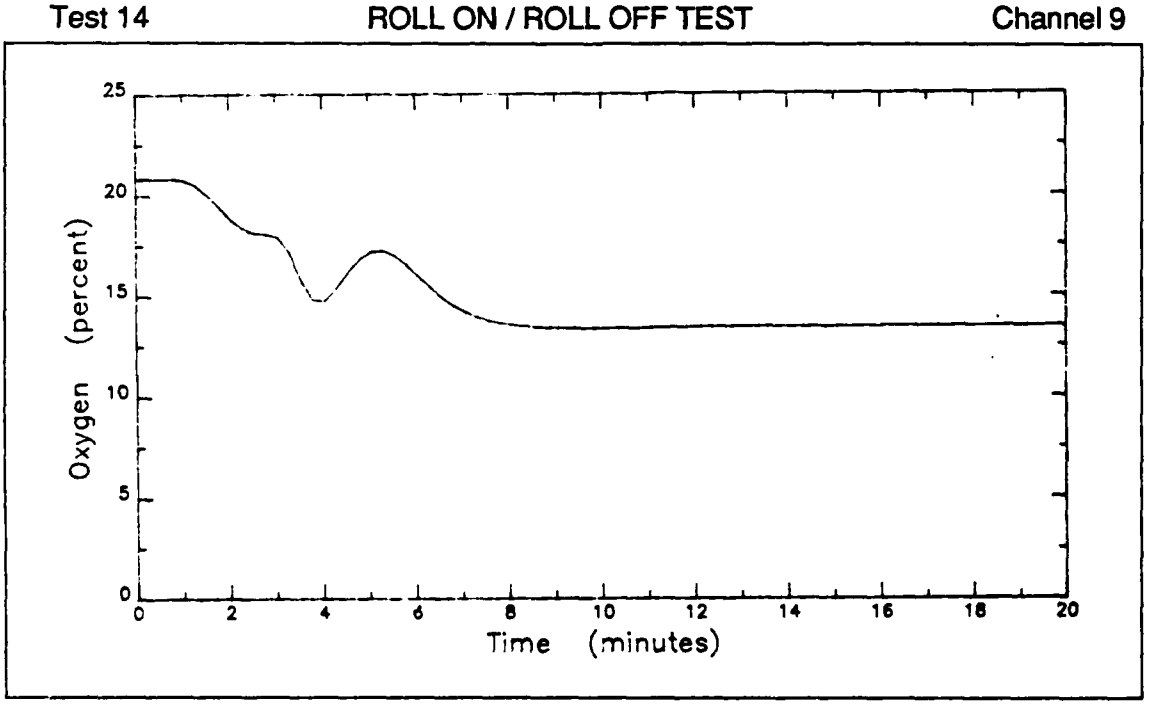
TEST 14

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 3.7 | 20.8 | 8.8 | 13.9 | 14.4% OXYGEN @ 7.1 MINUTES |
| 9 | Auto 10A | 3.7 | -- | -- | -- | |
| 10 | Auto 12A | 3.7 | 20.9 | 10.8 | 13.9 | 14.4% OXYGEN @ 7.8 MINUTES |
| 11 | Auto 11A | 3.7 | 18.5 | 8.0 | 15.1 | |
| 12 | Auto 9B | 3.7 | 17.6 | 7.5 | 15.0 | |
| 13 | | 3.7 | 19.3 | 9.3 | 16.5 | |
| | | AVERAGE | 19.4 | 8.9 | 14.9 | |

FIGURE B 14-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

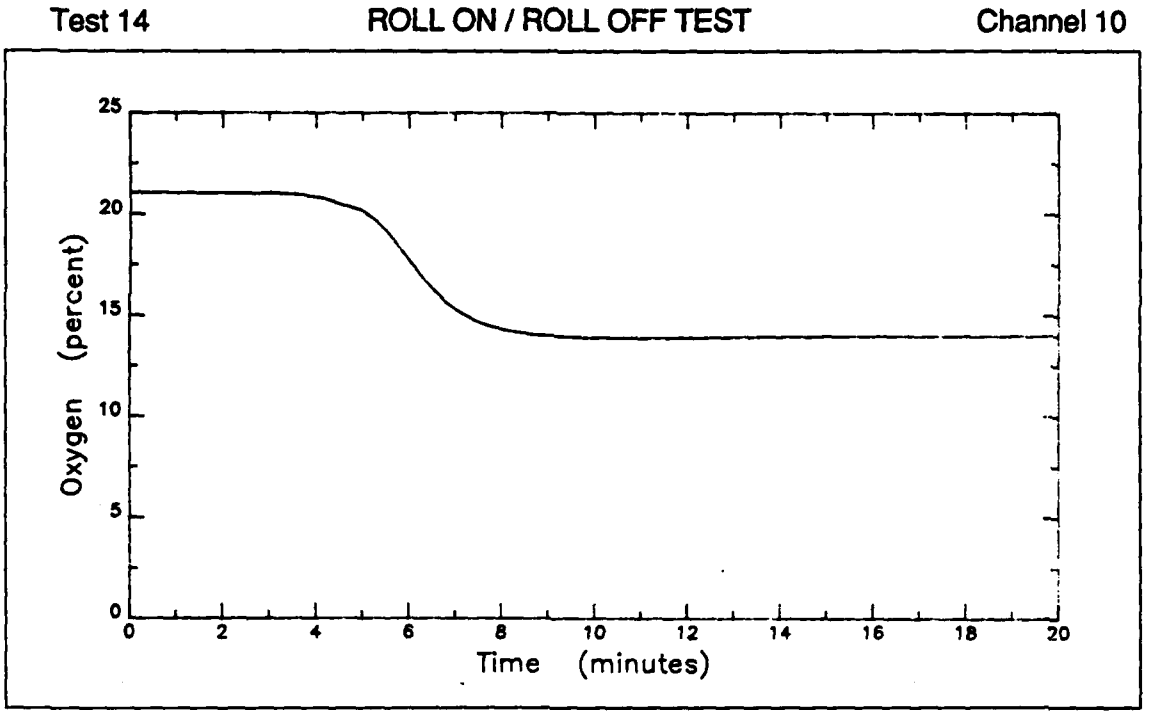



a. Test location - Automobile 9A

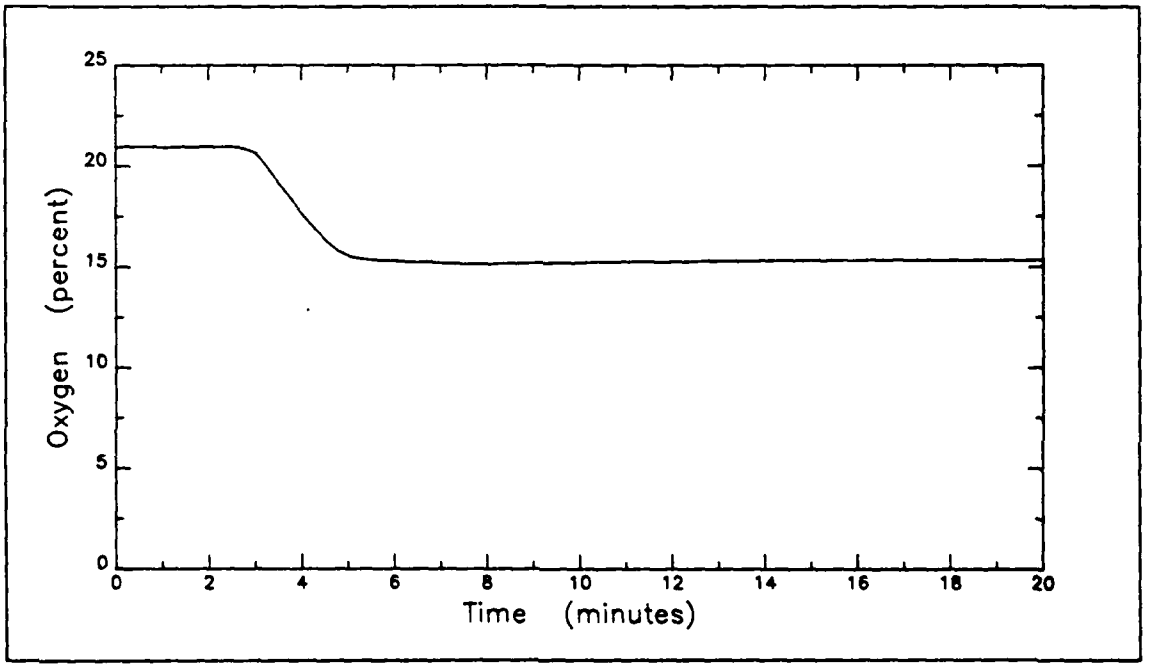



b. Test location - Automobile 10A

**FIGURE B 14-6. PERCENT OXYGEN vs TIME**

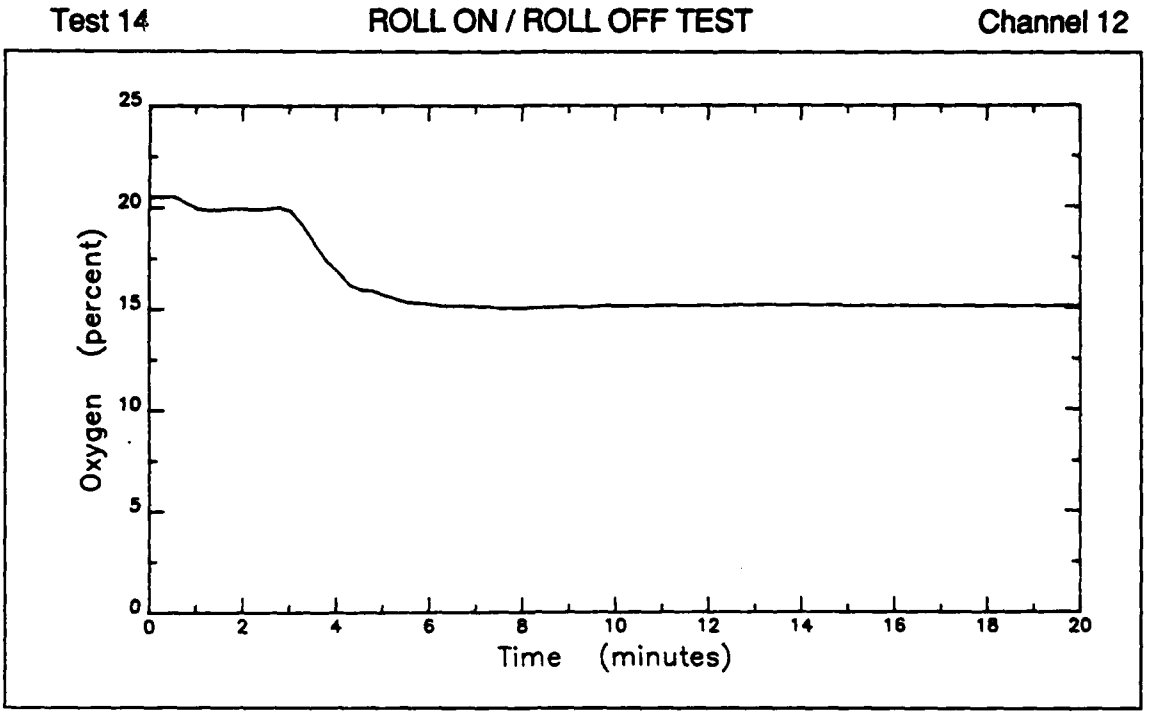



c. Test location - Automobile 11A

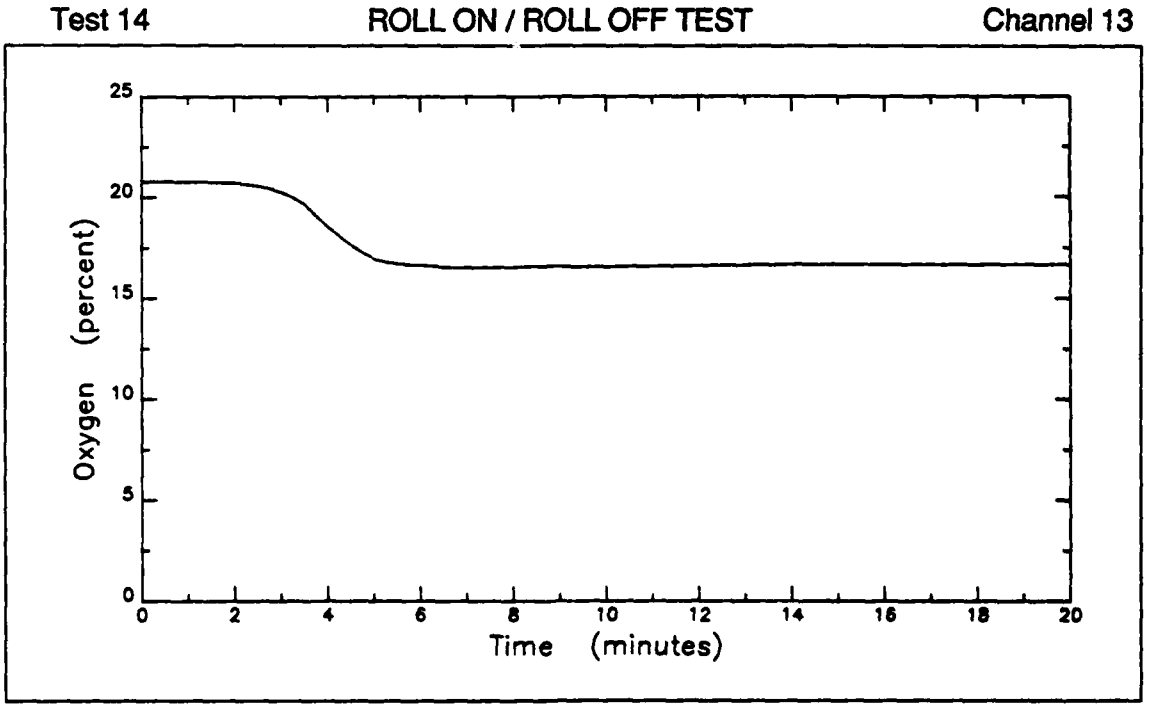



d. Test location - Automobile 12A

**FIGURE B 14-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B




f. Test location - Automobile 12B

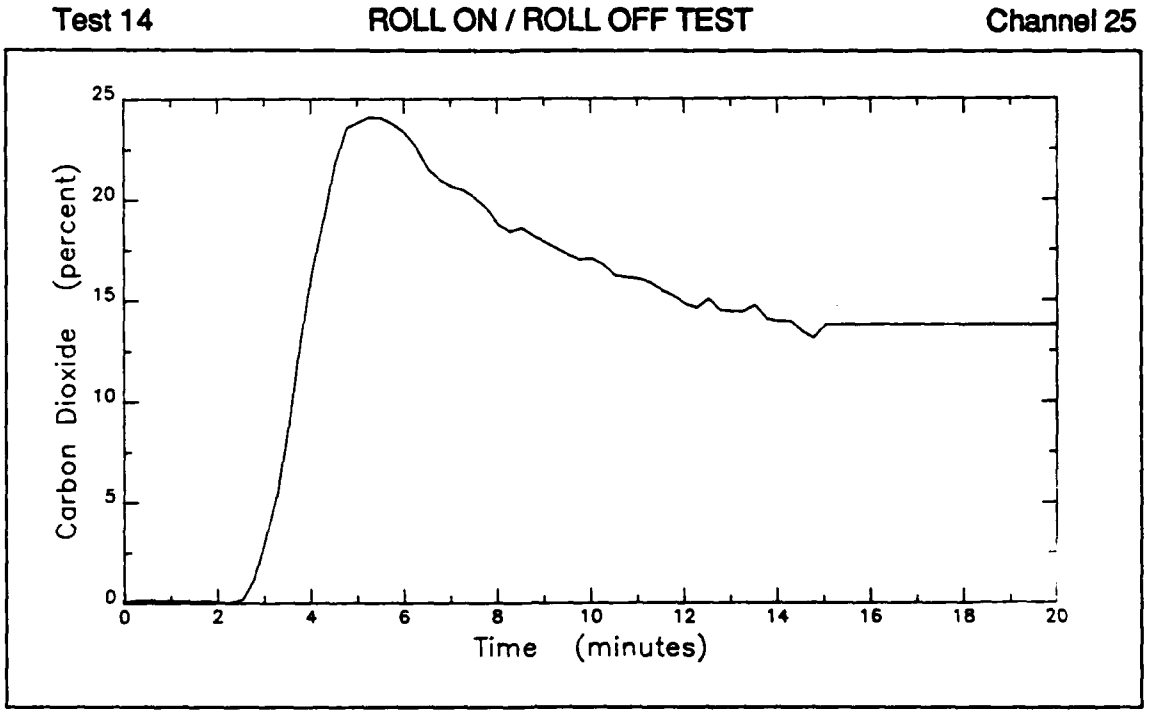
**FIGURE B 14-6. PERCENT OXYGEN vs TIME (cont'd)**

TEST 14

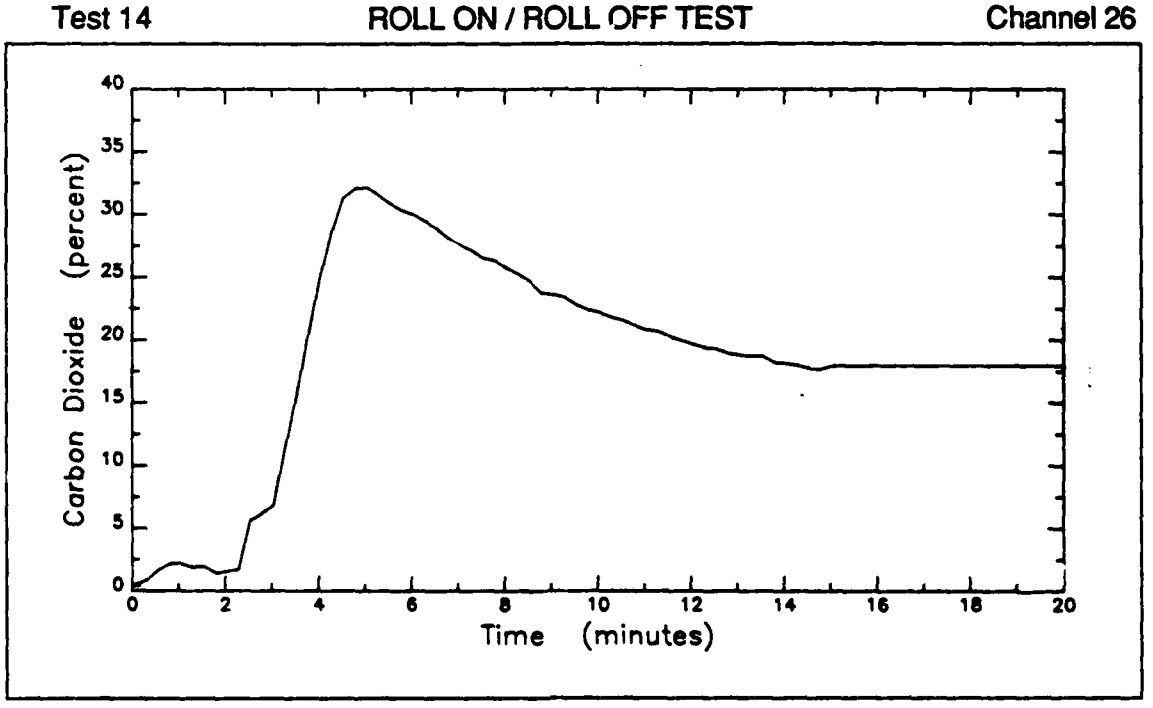
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 3.7 | 12.1 | 5.3 | 24.1 | |
| 26 | Auto 10A | 3.7 | 17.3 | 5.0 | 32.3 | |
| 27 | Auto 11A | 3.7 | 16.4 | 7.8 | 35.8 | |
| 28 | Auto 12A | 3.7 | 19.7 | 4.5 | 32.4 | |
| 29 | Auto 9C | 3.7 | 10.5 | 6.5 | 28.8 | |
| 30 | Auto 3A | 3.7 | 5.1 | 6.8 | 24.3 | |
| 31 | Auto 9B | 3.7 | 14.7 | 7.5 | 38.4 | |
| 32 | Auto 12B | 3.7 | 14.5 | 15.0 | 38.9 | |
| 33 | Auto 3B | 3.7 | 10.2 | 7.3 | 27.4 | |
| | | AVERAGE | 13.4 | 6.3 | 30.4 | |



FIGURE B 14-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

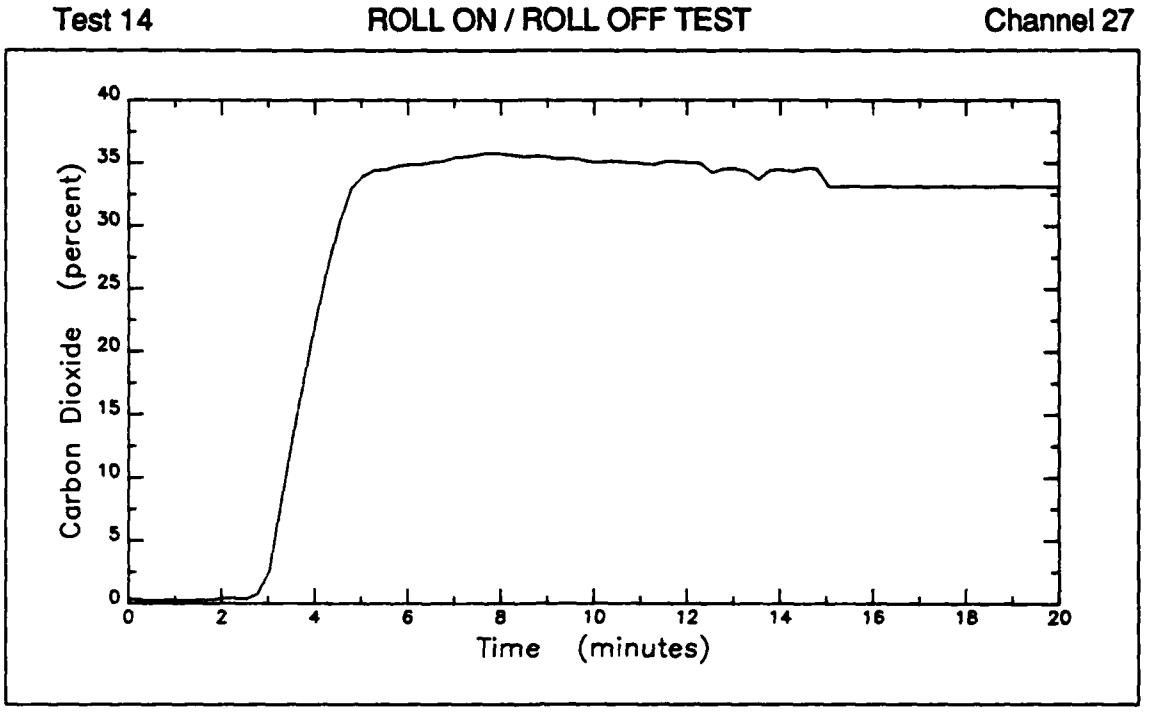



a. Test location - Automobile 9A

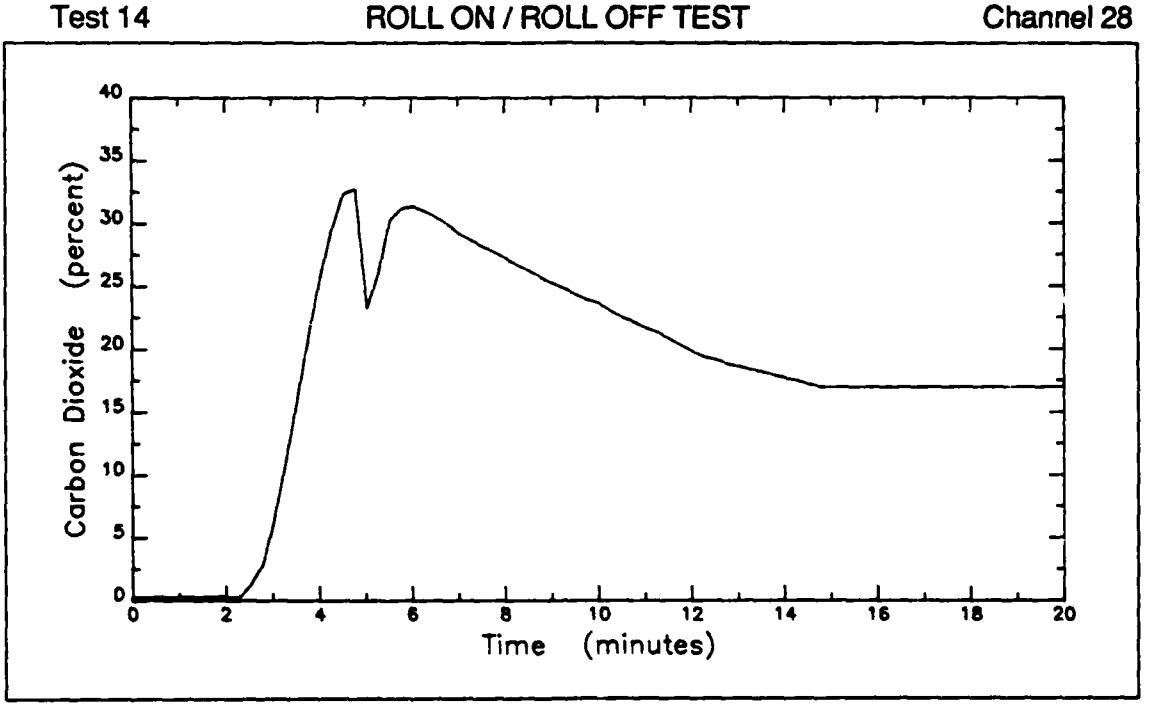



b. Test location - Automobile 10A

**FIGURE B 14-8. PERCENT CARBON DIOXIDE vs TIME**

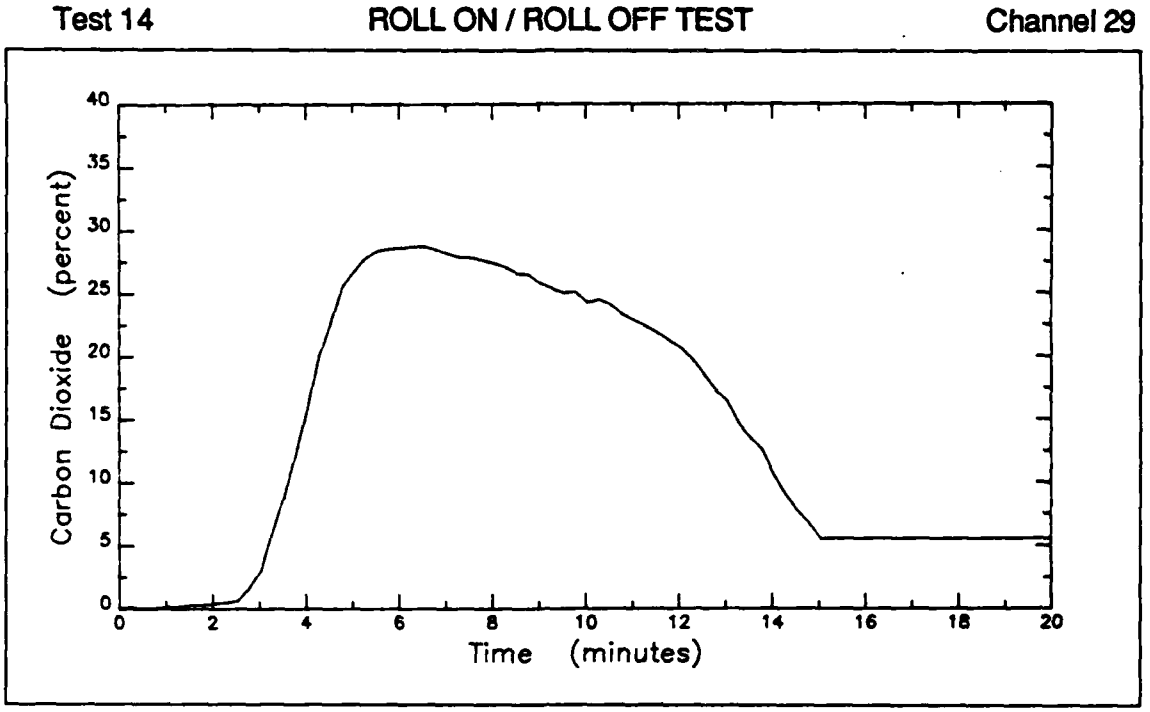



c. Test location - Automobile 11A

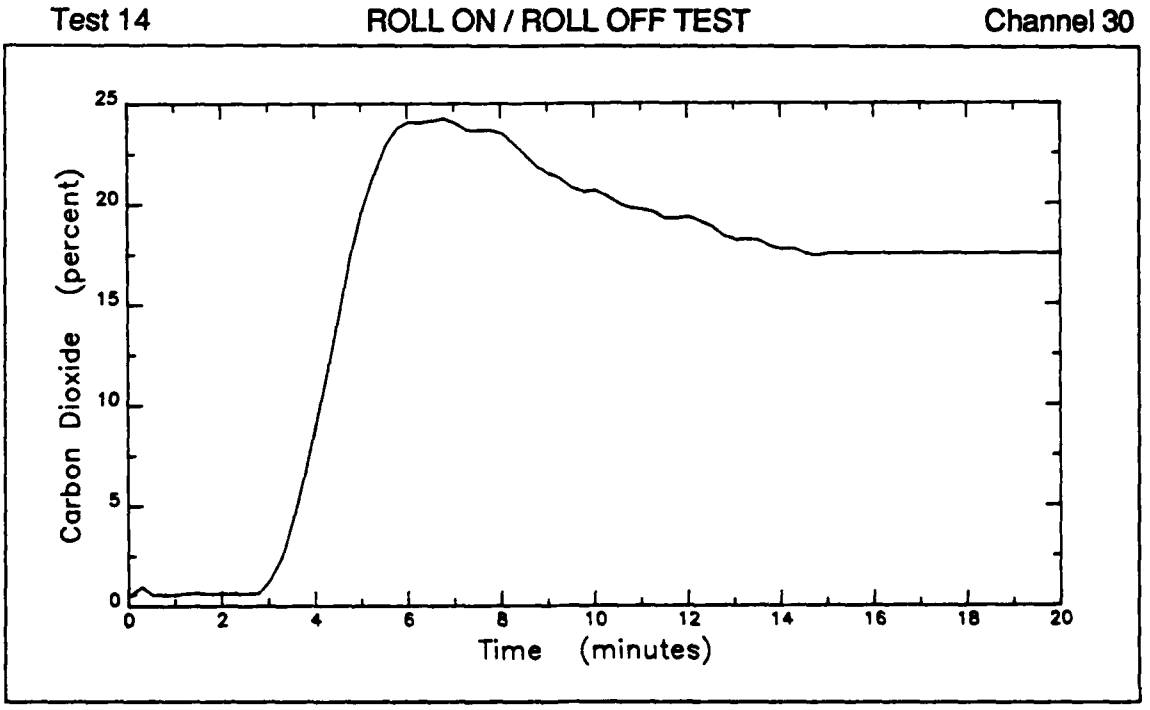



d. Test location - Automobile 12A

**FIGURE B 14-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

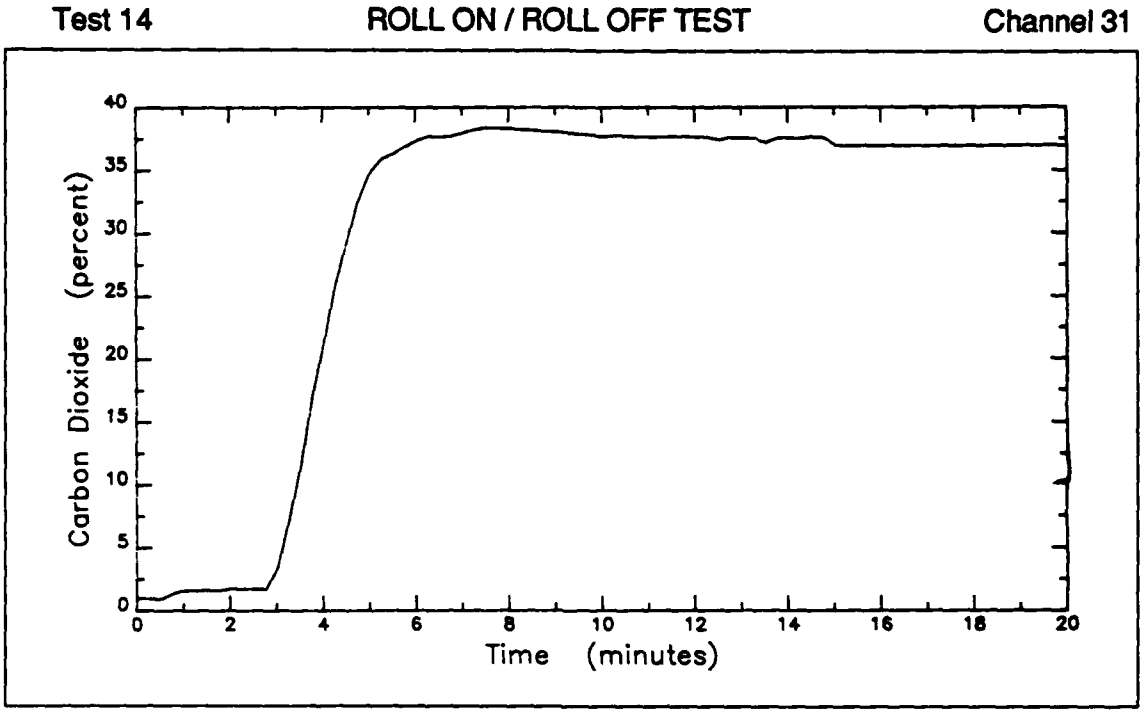



e. Test location - Automobile 9C

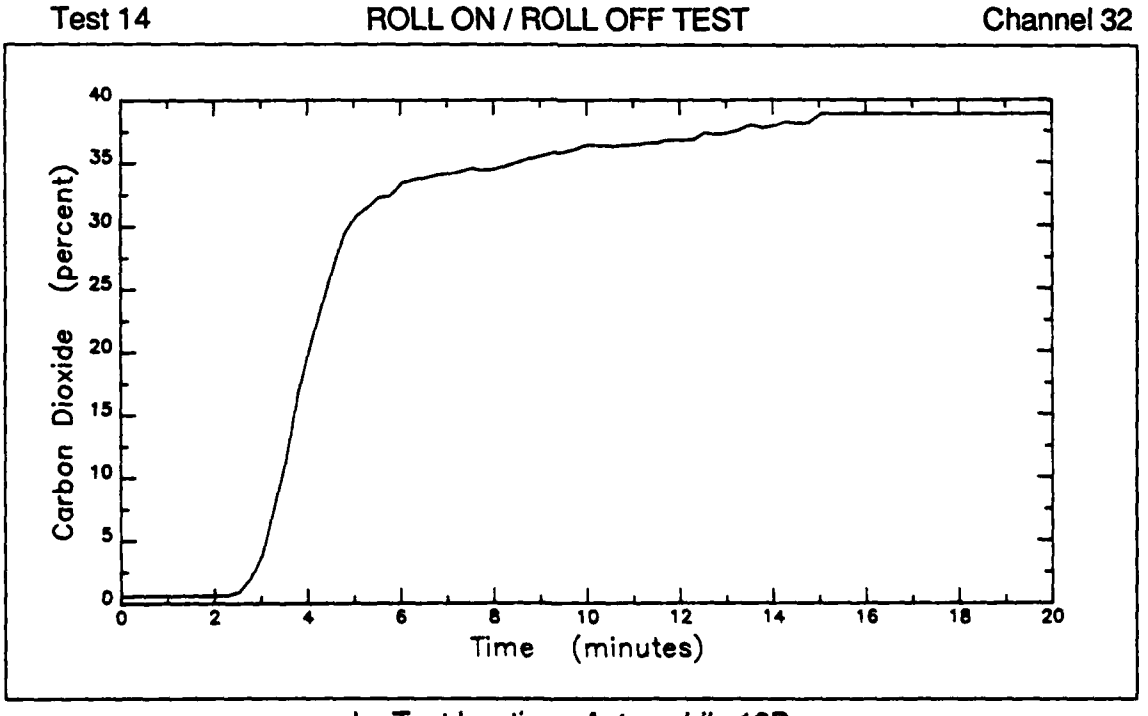



f. Test location - Automobile 3B

**FIGURE B 14-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

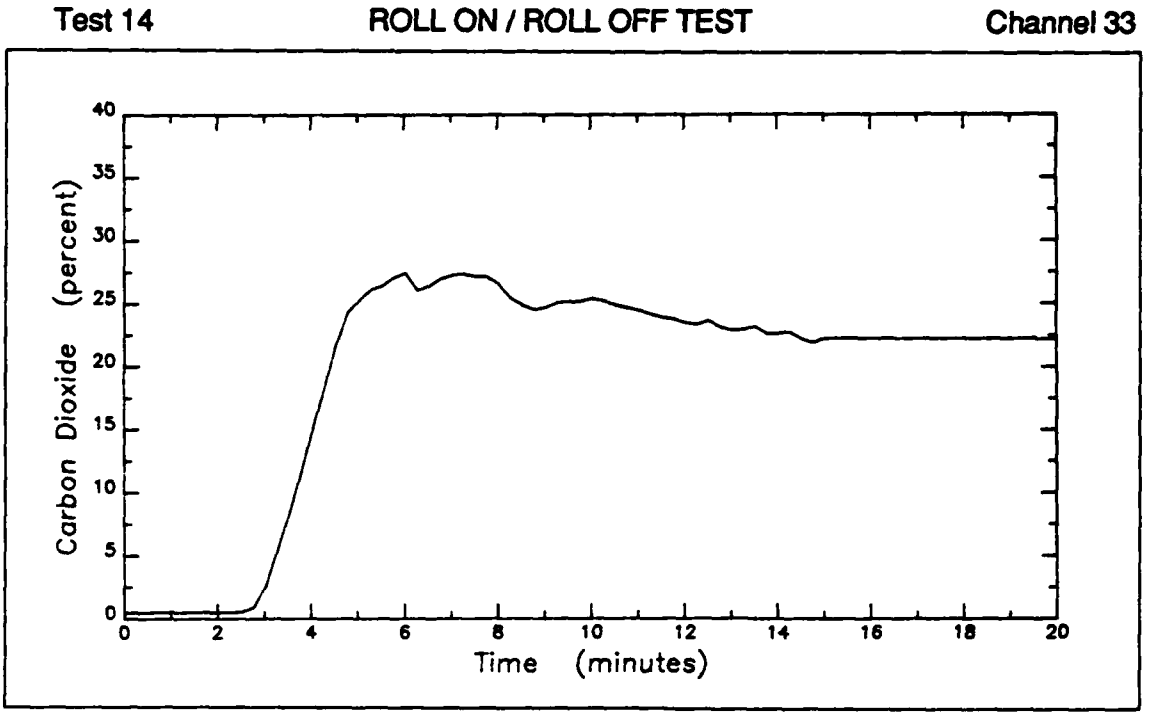



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 14-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

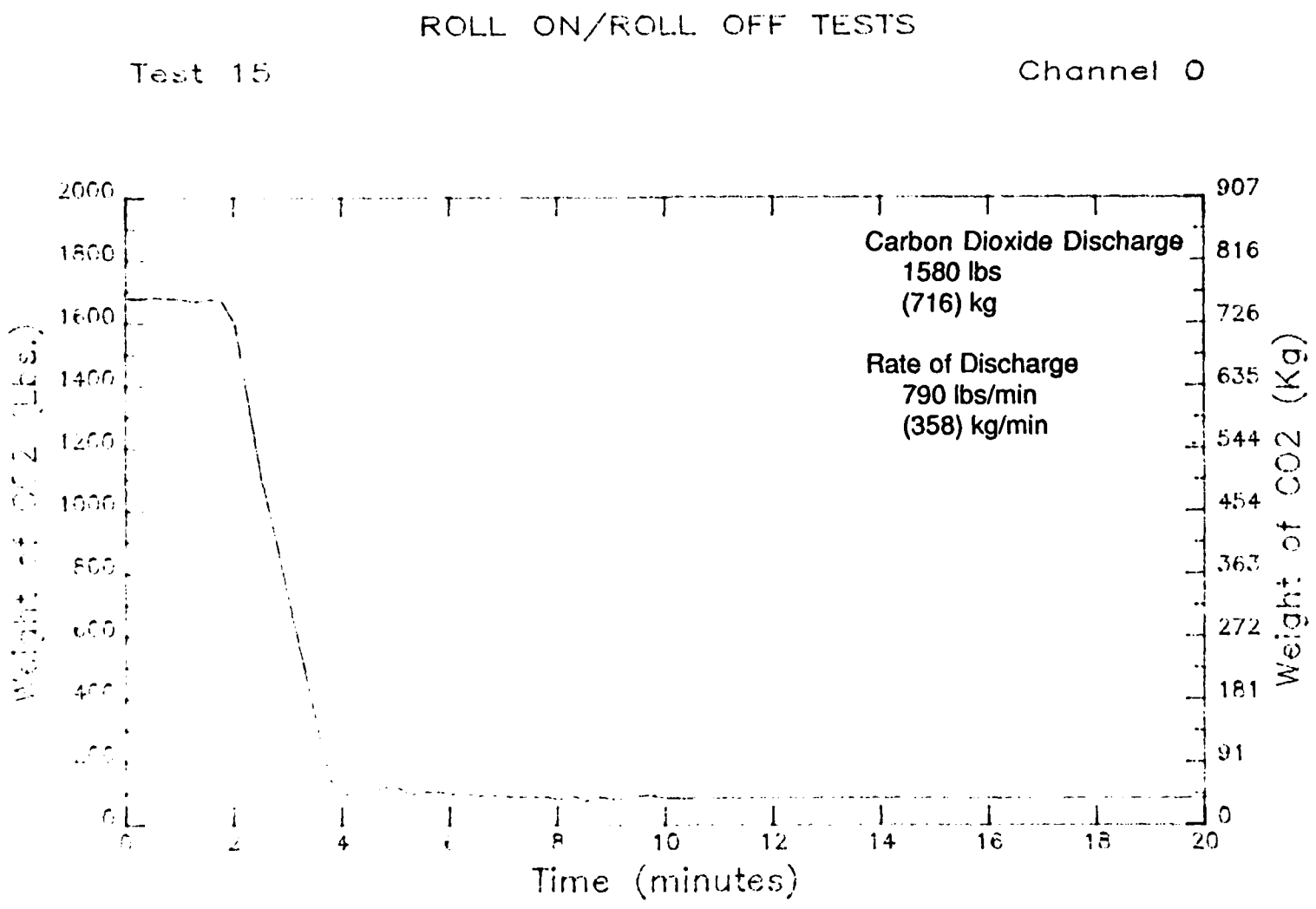



i. Test location - Automobile 3B

**FIGURE B 14-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

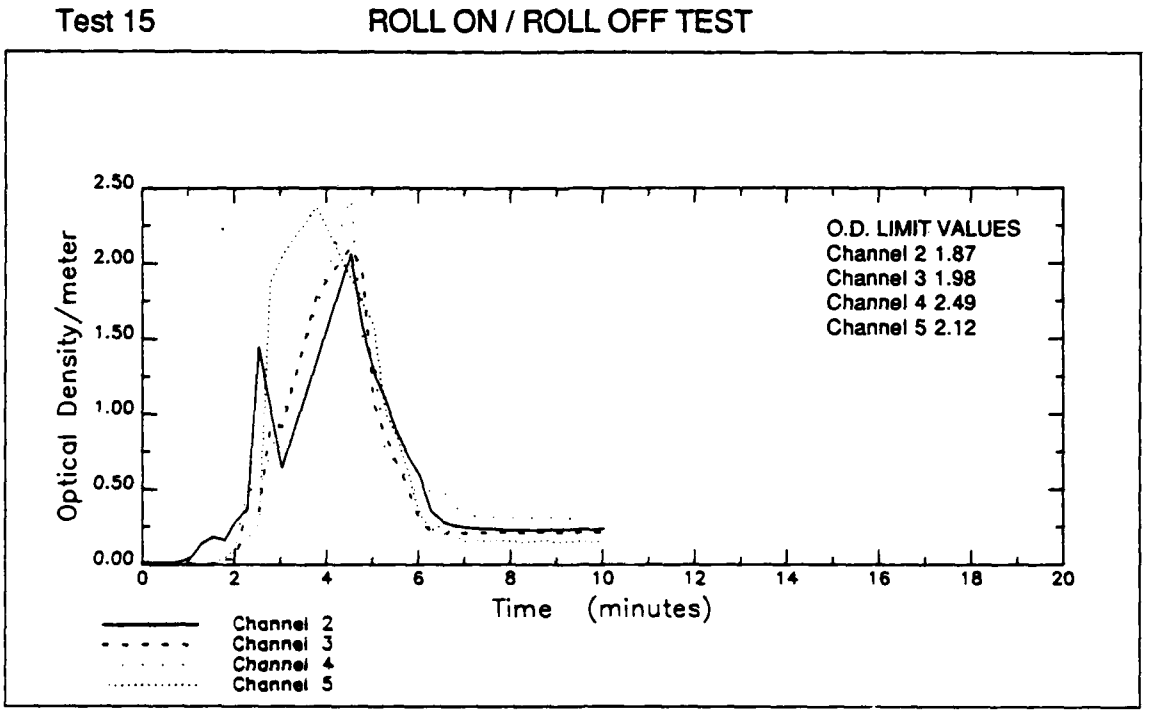
# APPENDIX B

# TEST 15

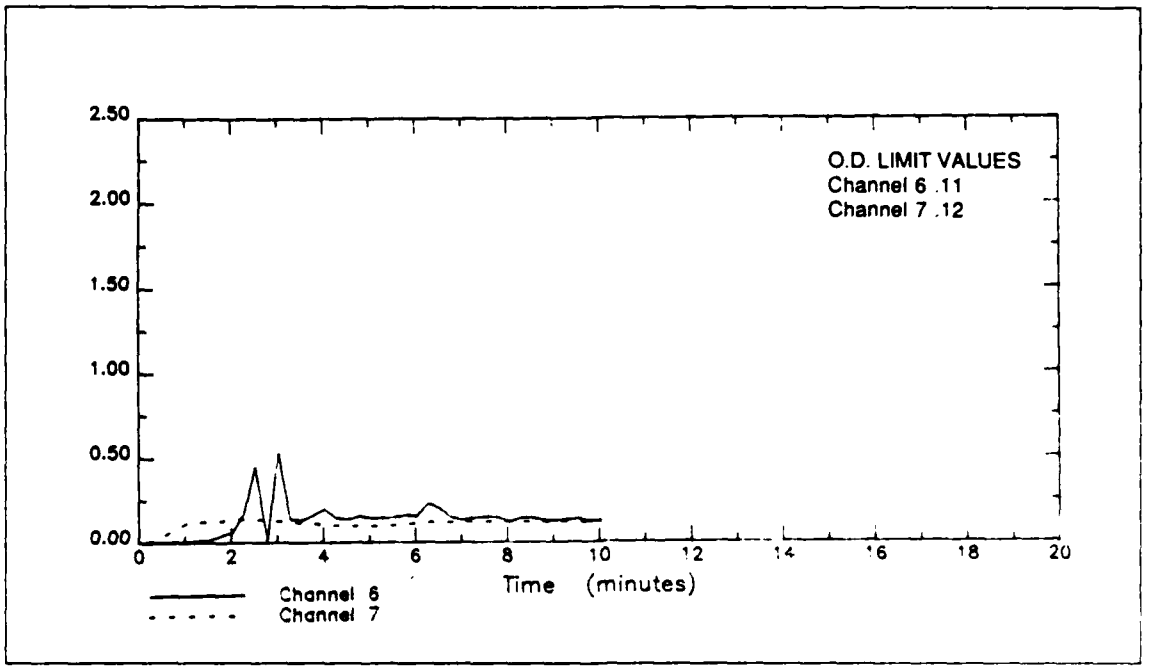



B 15-1

FIGURE B 15-1. Weight of Carbon Dioxide vs Time

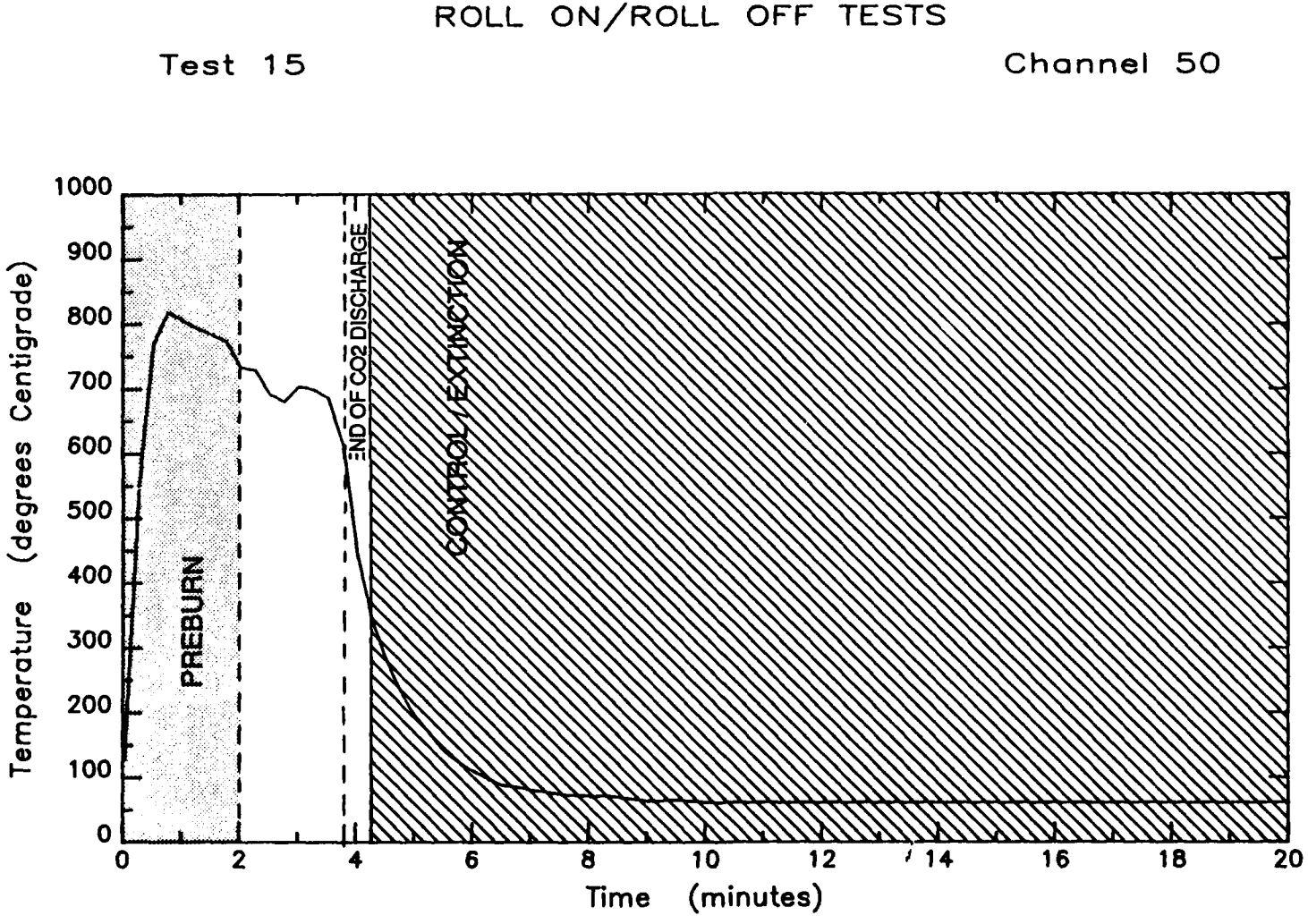



a. Data Channels 2,3,4,5



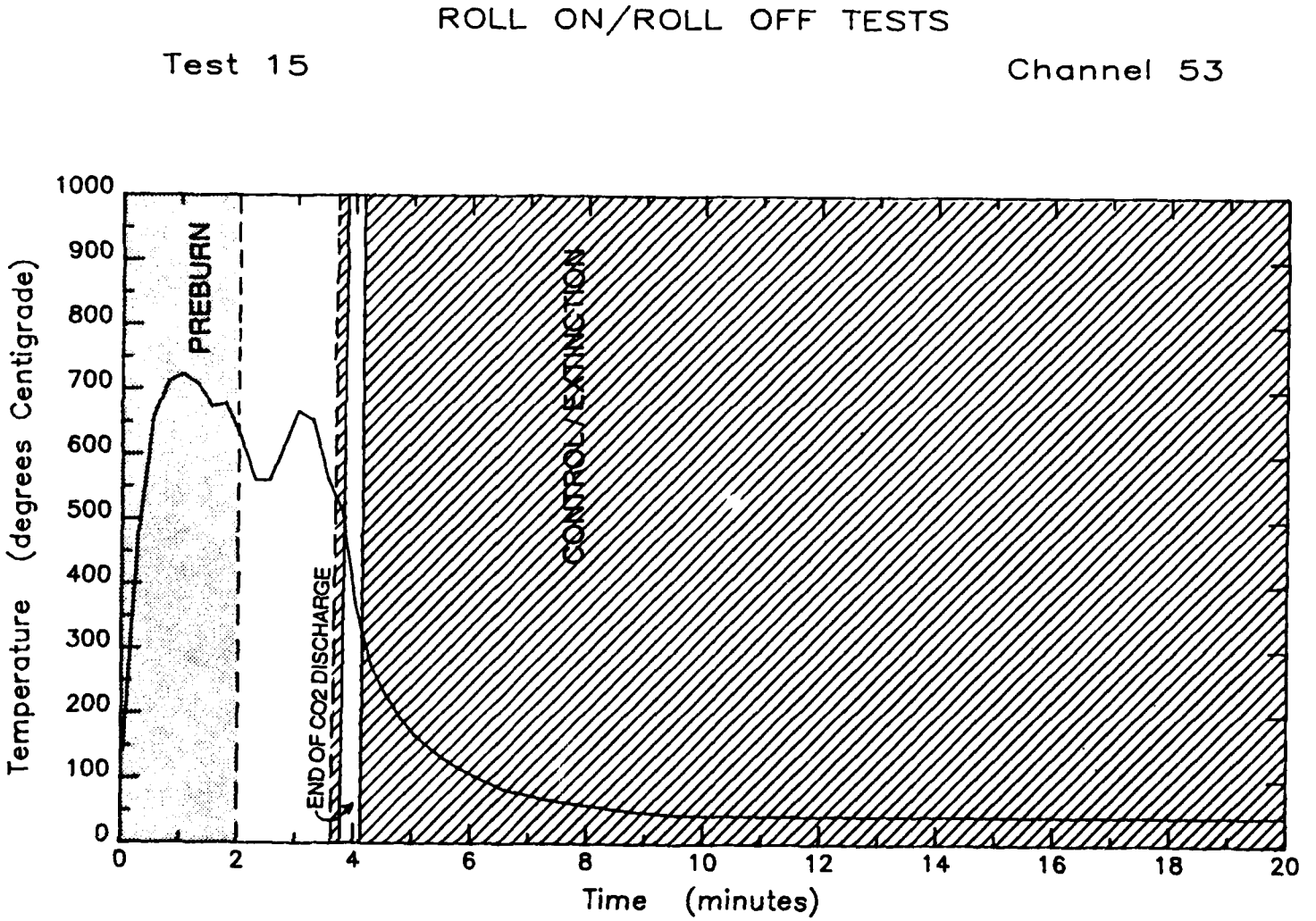

b. Data Channels 6, 7

**FIGURE 15-2. OPTICAL DENSITY vs TIME**




B 15-3

FIGURE B 15-3. Temperature vs Time - Location 9A



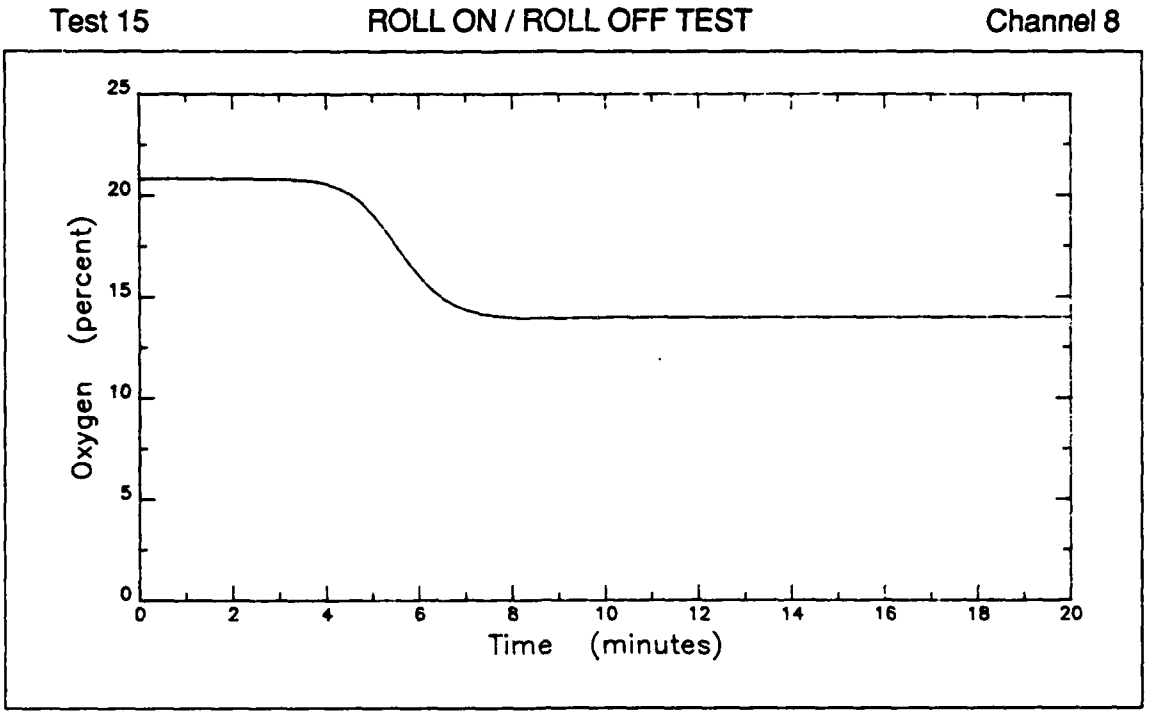

B 15-4

FIGURE B 15-4. Temperature vs Time - Location 10A

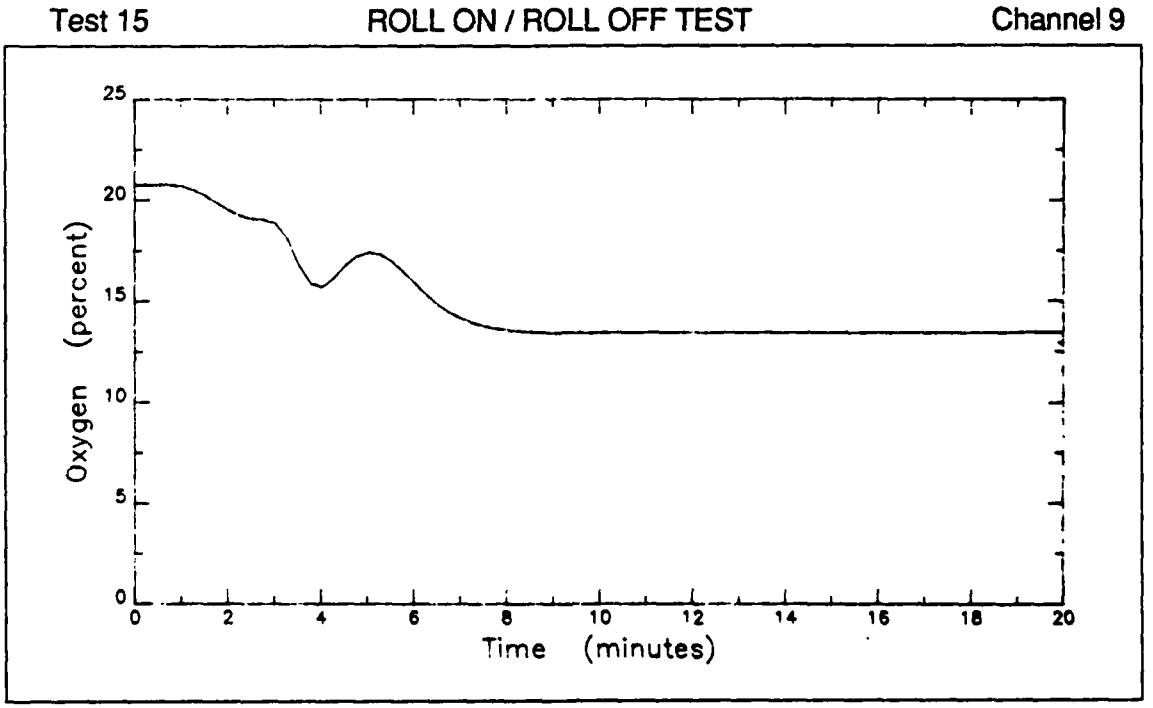
TEST 15

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 3.8 | 20.6 | 8.8 | 13.9 | 14.4% OXYGEN @ 6.8 MINUTES |
| 9 | Auto 10A | 3.8 | -- | -- | -- | |
| 10 | Auto 12A | 3.8 | 20.8 | 10.0 | 13.9 | |
| 11 | Auto 11A | 3.8 | 17.9 | 8.0 | 15.1 | |
| 12 | Auto 9B | 3.8 | 17.2 | 7.5 | 15.0 | |
| 13 | | 3.8 | 18.5 | 6.8 | 16.6 | |
| | | AVERAGE | 19.0 | 7.8 | 15.1 | |

FIGURE B 15-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

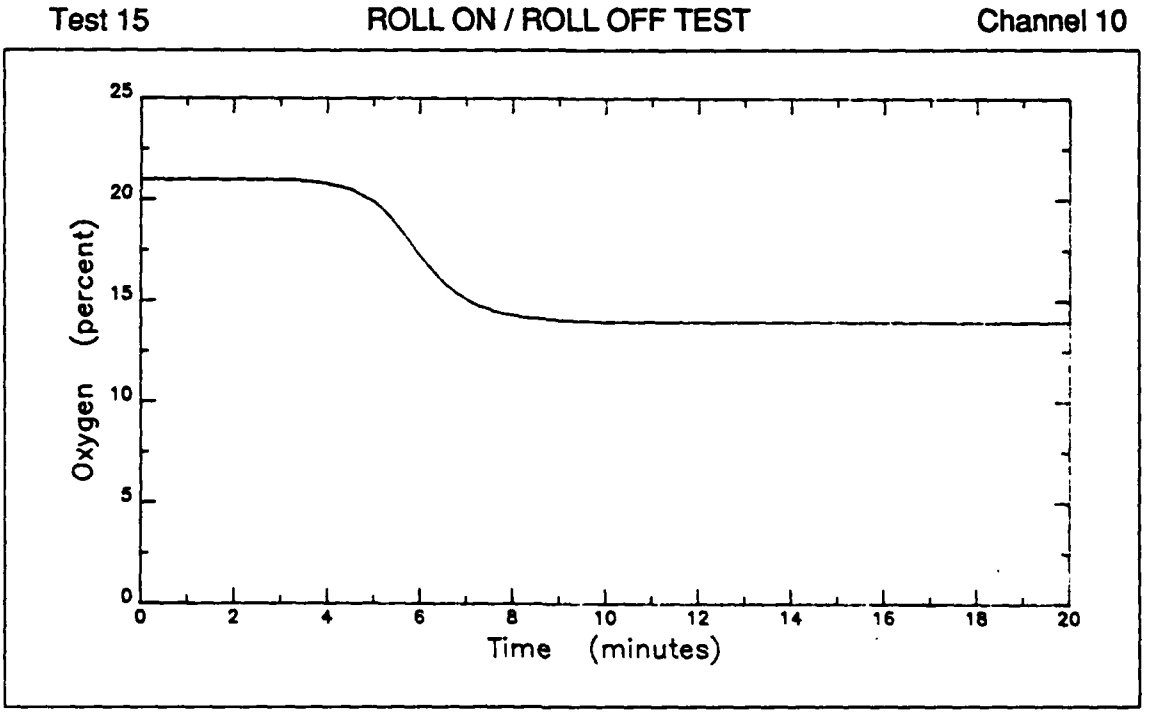



a. Test location - Automobile 9A

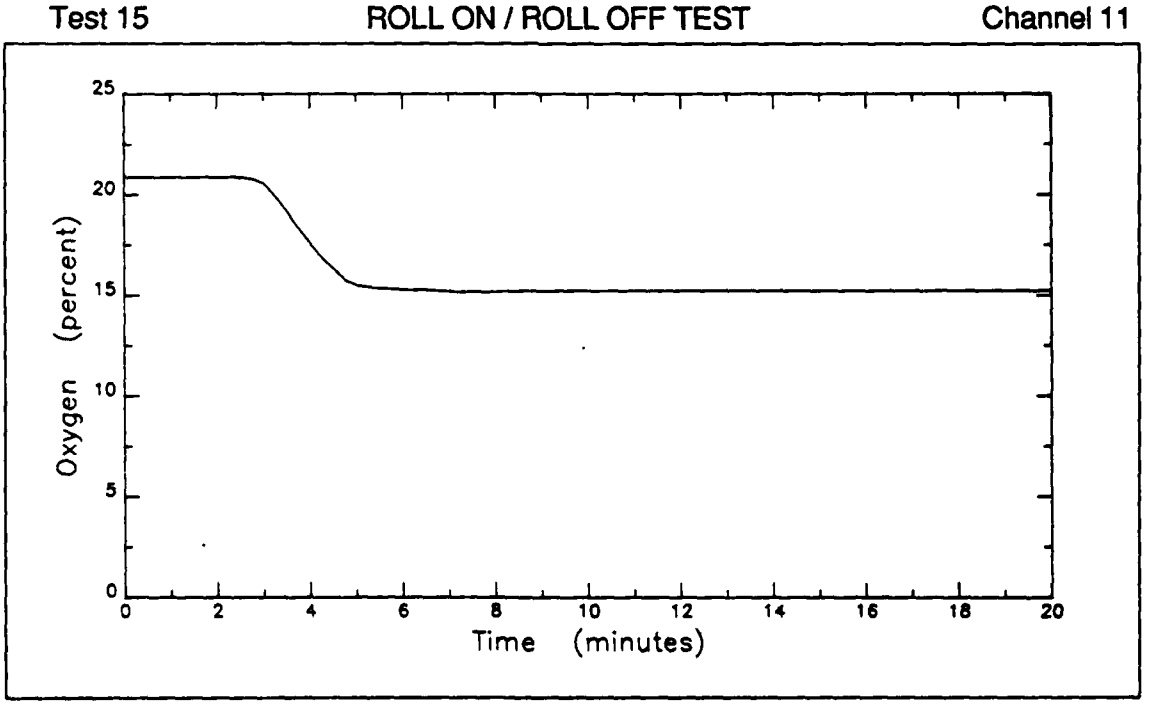



b. Test location - Automobile 10A

**FIGURE B 15-6. PERCENT OXYGEN vs TIME**

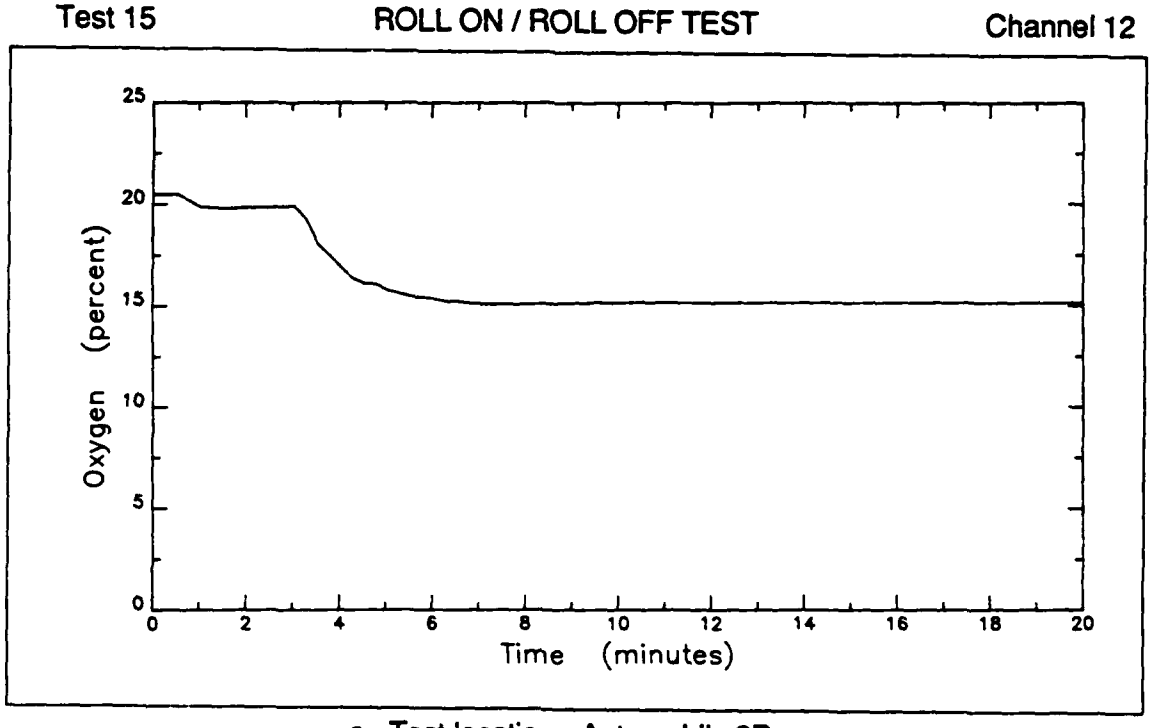



c. Test location - Automobile 11A

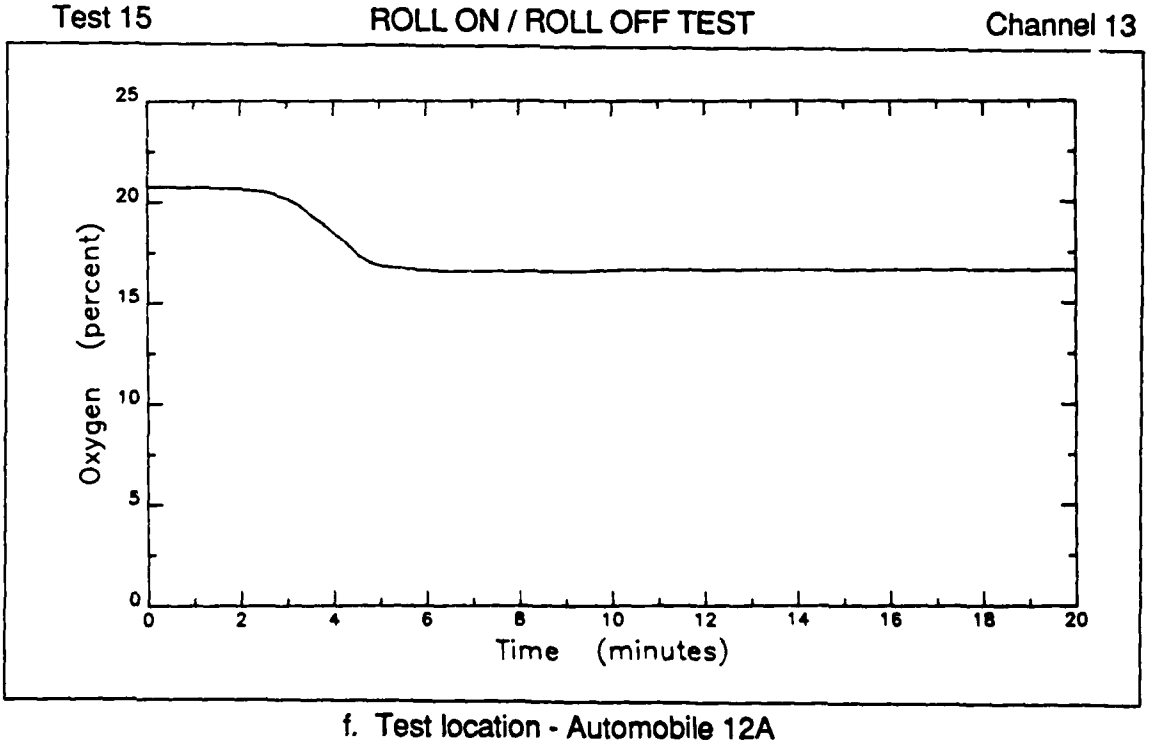



d. Test location - Automobile 12A

**FIGURE B 15-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B



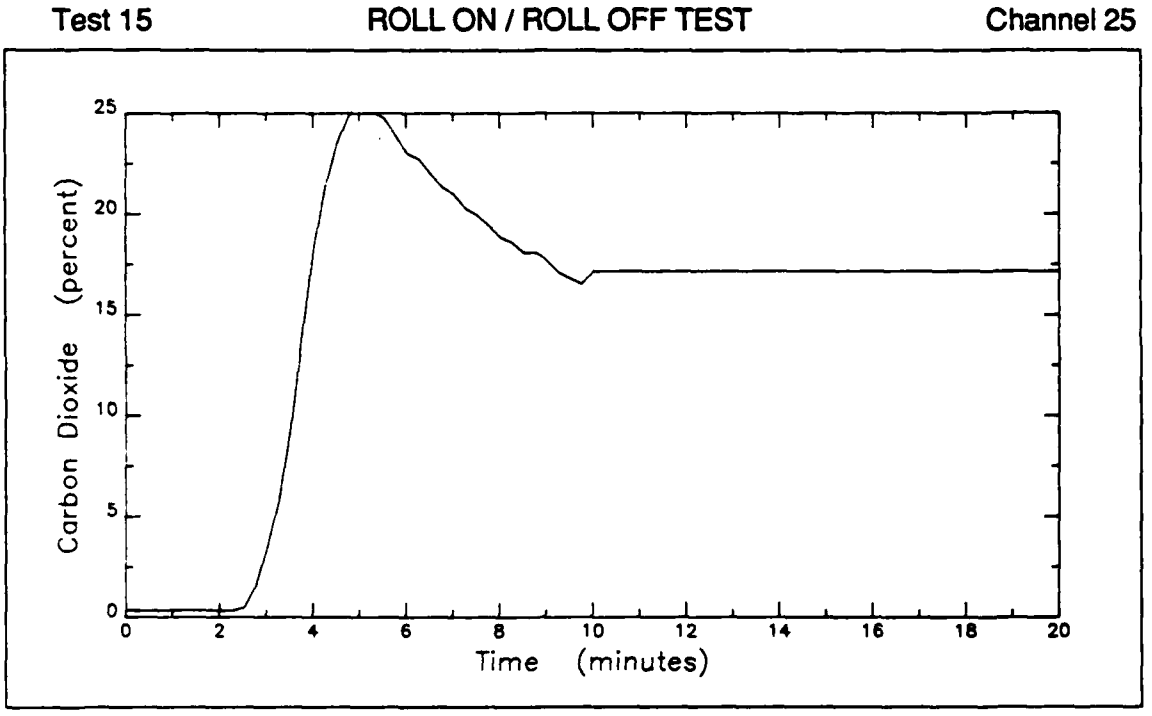

f. Test location - Automobile 12A

**FIGURE B 15-6. PERCENT OXYGEN vs TIME (cont'd)**

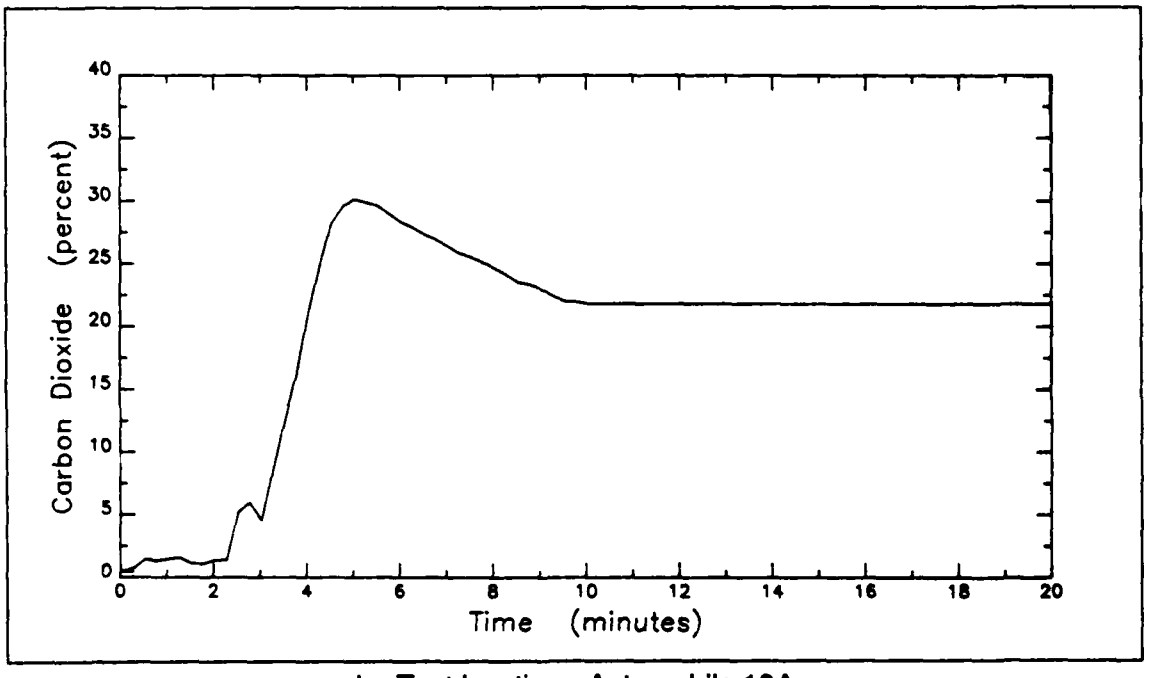
TEST 15

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 3.8 | 15.3 | 5.0 | 25.3 | |
| 26 | Auto 10A | 3.8 | 17.4 | 5.0 | 30.1 | |
| 27 | Auto 11A | 3.8 | 18.6 | 7.3 | 35.0 | |
| 28 | Auto 12A | 3.8 | 22.5 | 4.5 | 32.1 | |
| 29 | Auto 9C | 3.8 | 12.1 | 6.0 | 26.9 | |
| 30 | Auto 3A | 3.8 | 8.7 | 7.0 | 24.1 | |
| 31 | Auto 9B | 3.8 | 17.6 | 7.3 | 37.7 | |
| 32 | Auto 12B | 3.8 | 18.4 | 10.0 | 36.2 | |
| 33 | Auto 3B | 3.8 | 4.9 | 7.0 | 27.2 | |
| | | AVERAGE | 15.1 | 6.1 | 29.8 | |

FIGURE B 15-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

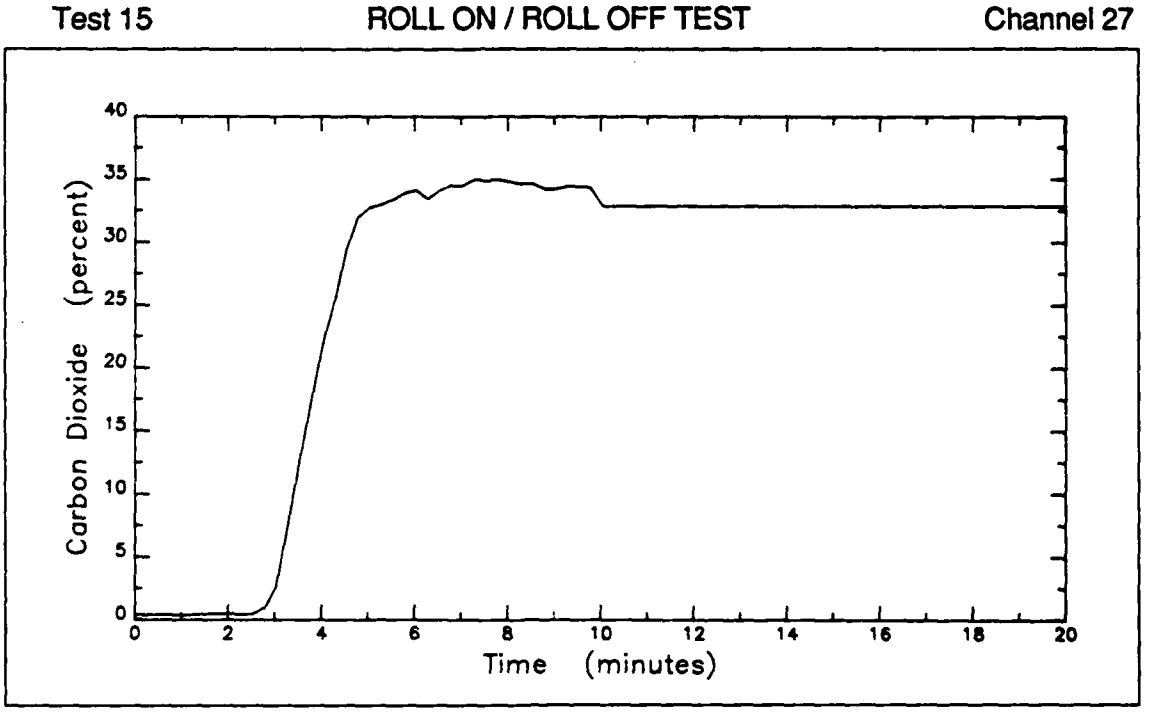



a. Test location - Automobile 9A

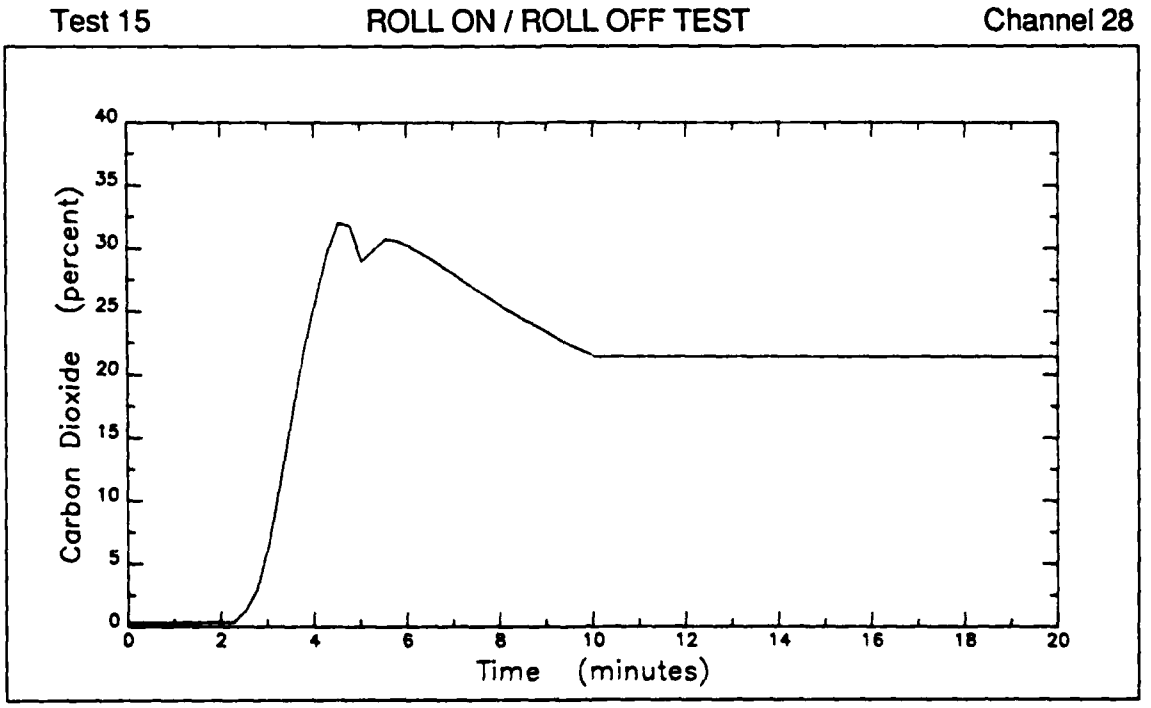



b. Test location - Automobile 10A

**FIGURE B 15-8. PERCENT CARBON DIOXIDE vs TIME**

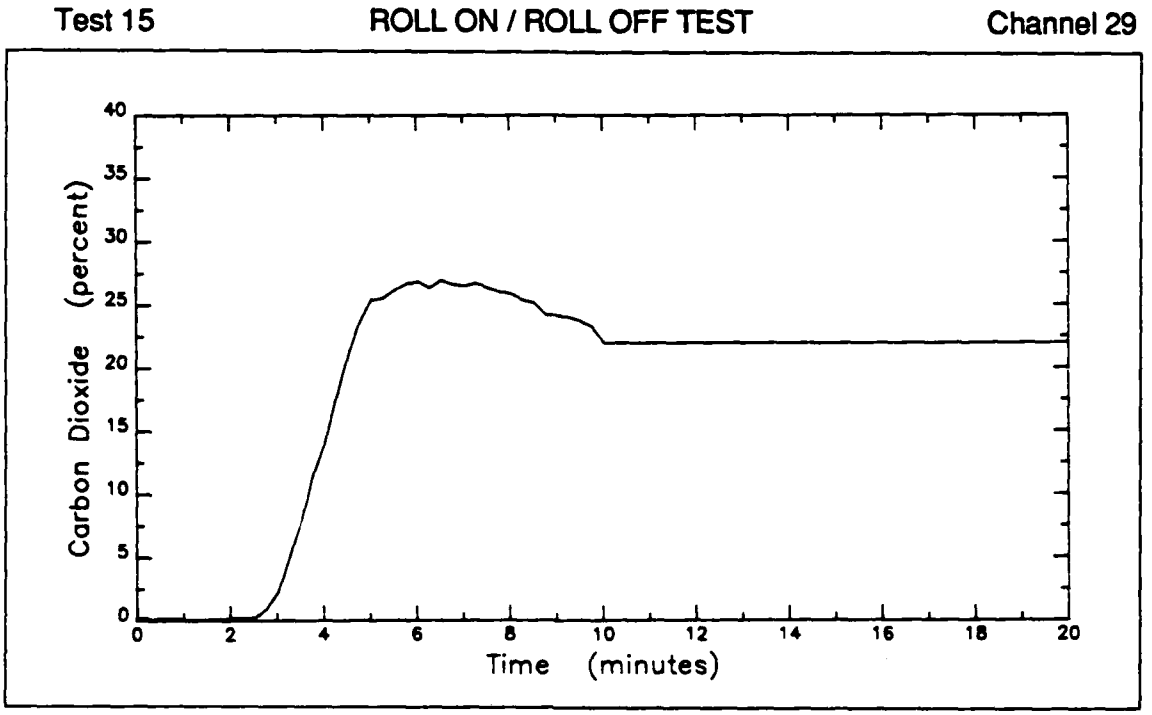



c. Test location - Automobile 11A

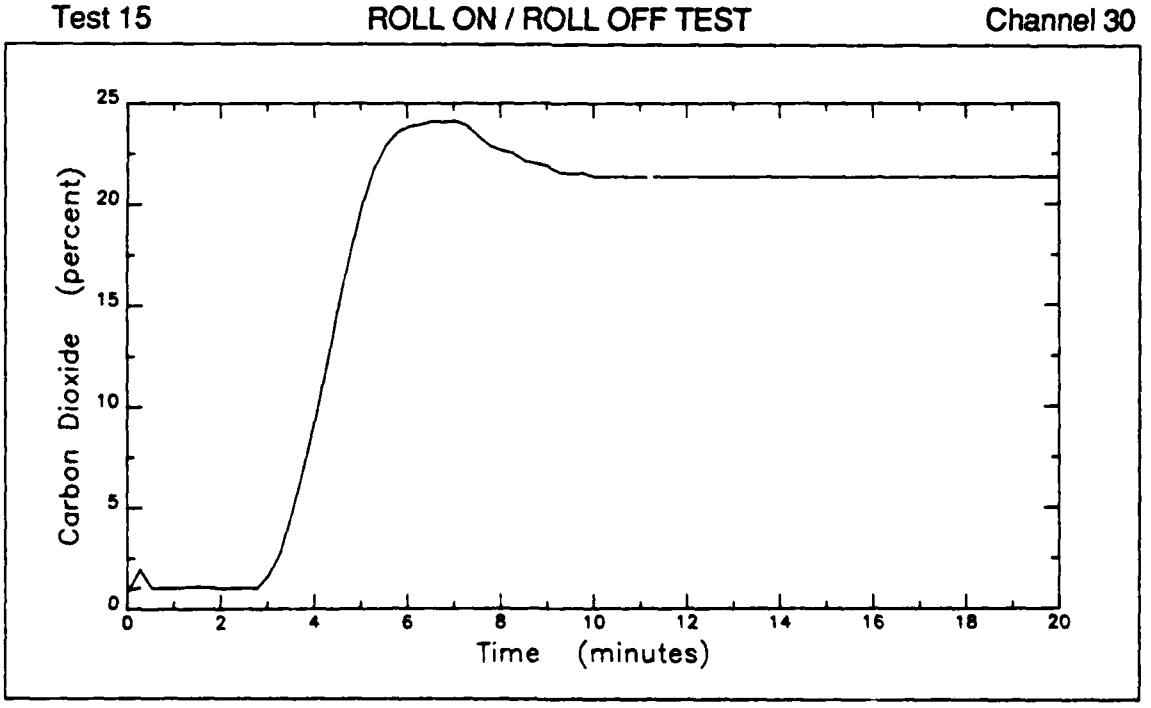



d. Test location - Automobile 12A

**FIGURE B 15-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

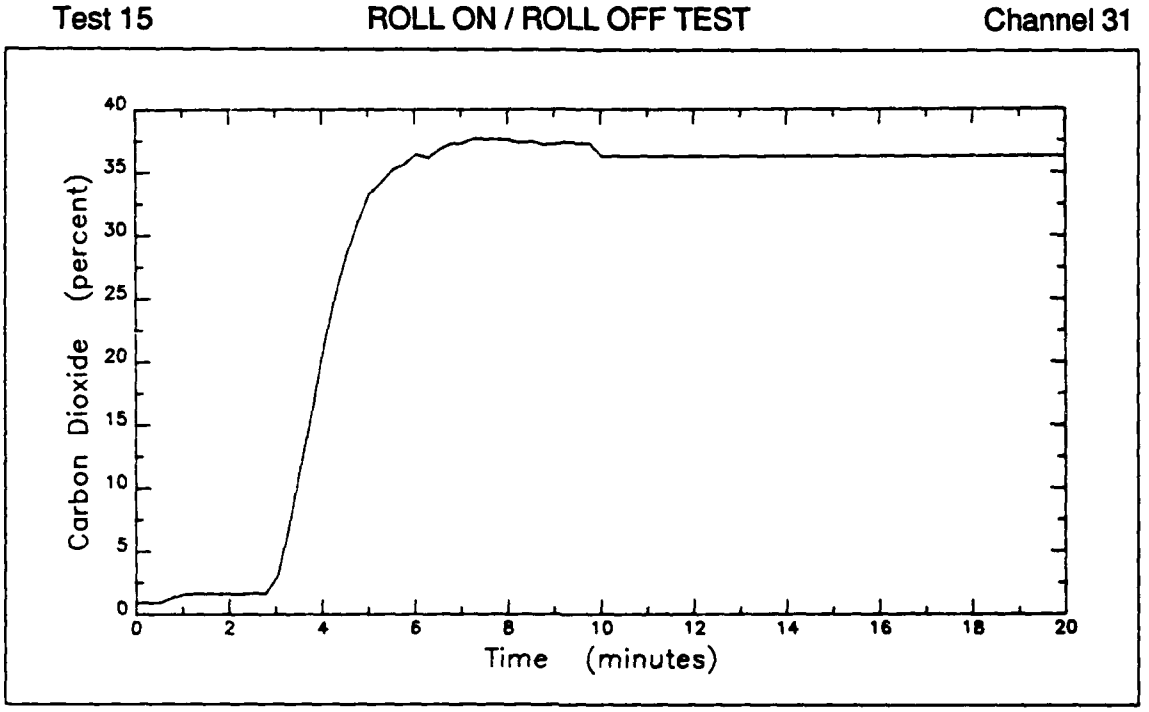



e. Test location - Automobile 9C

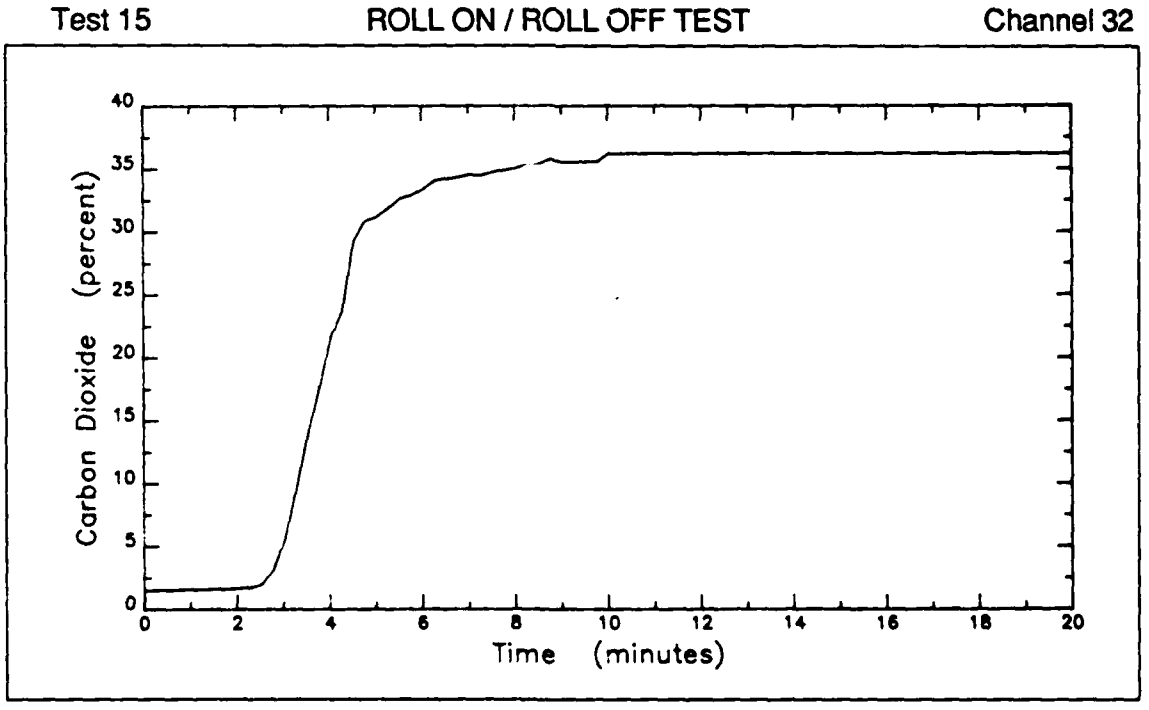



f. Test location - Automobile 3A

**FIGURE B 15-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

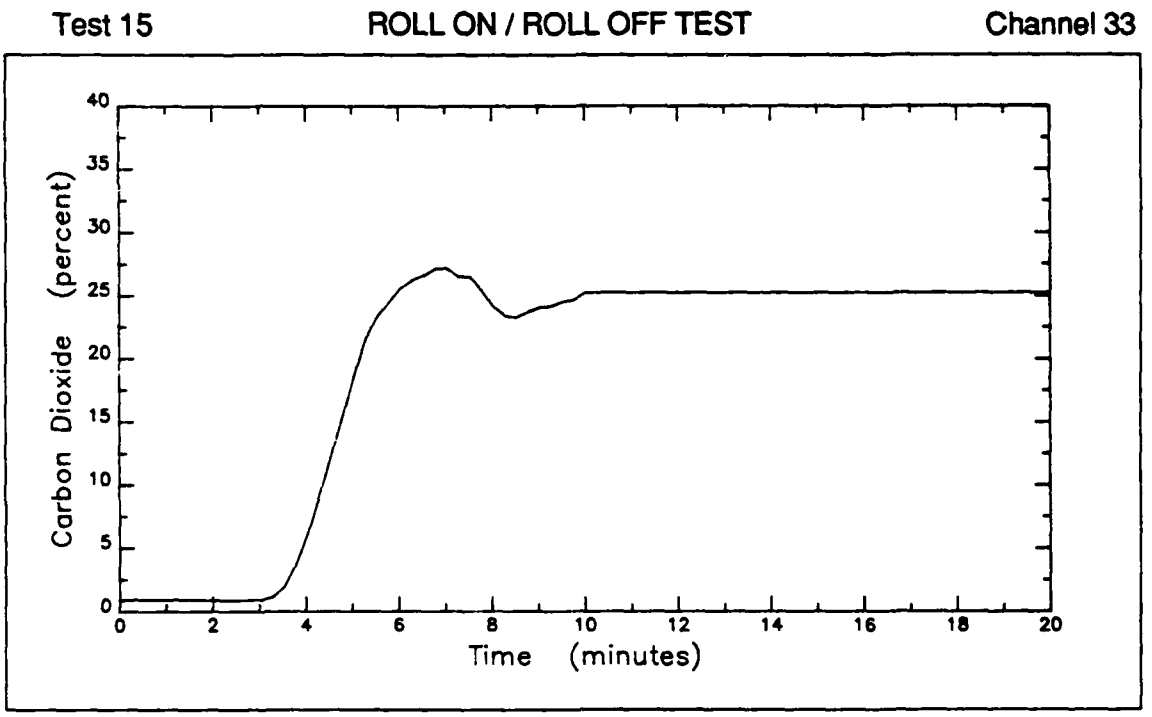



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 15-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 15-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX B

# TEST 16

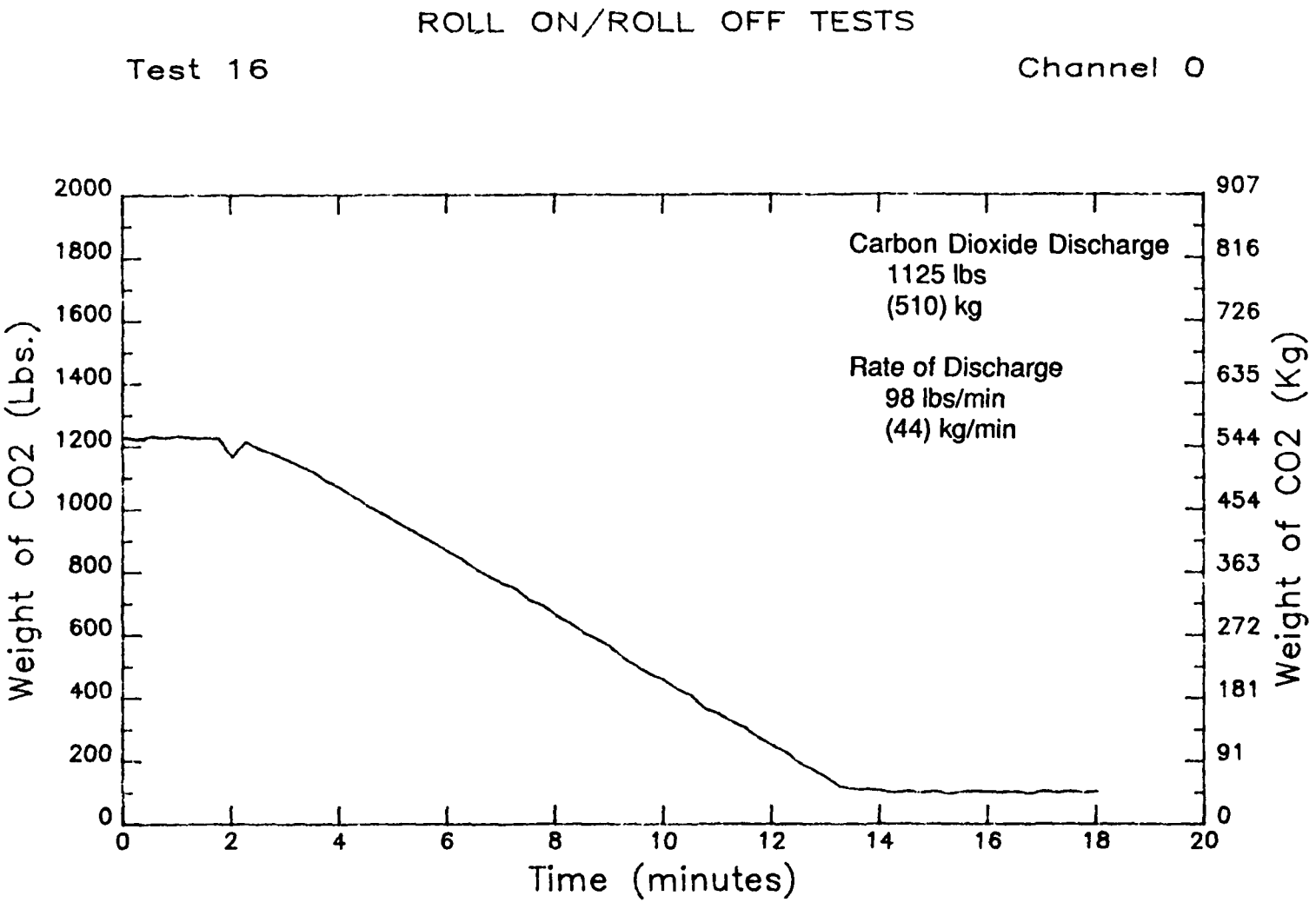
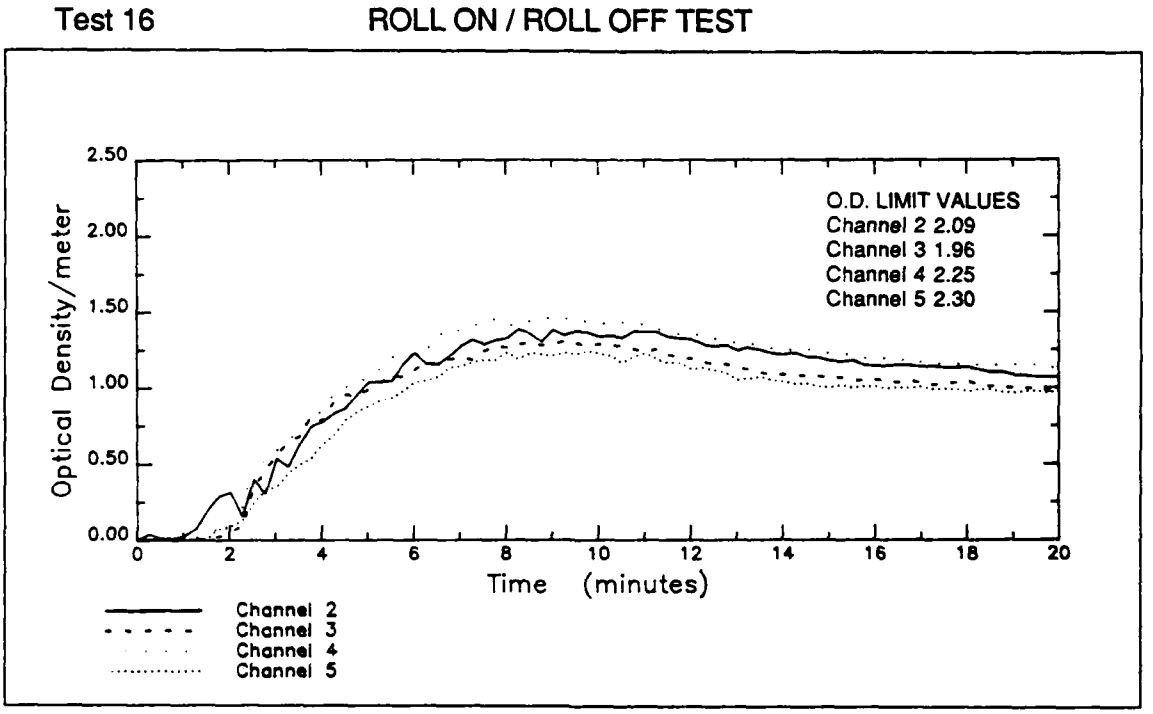
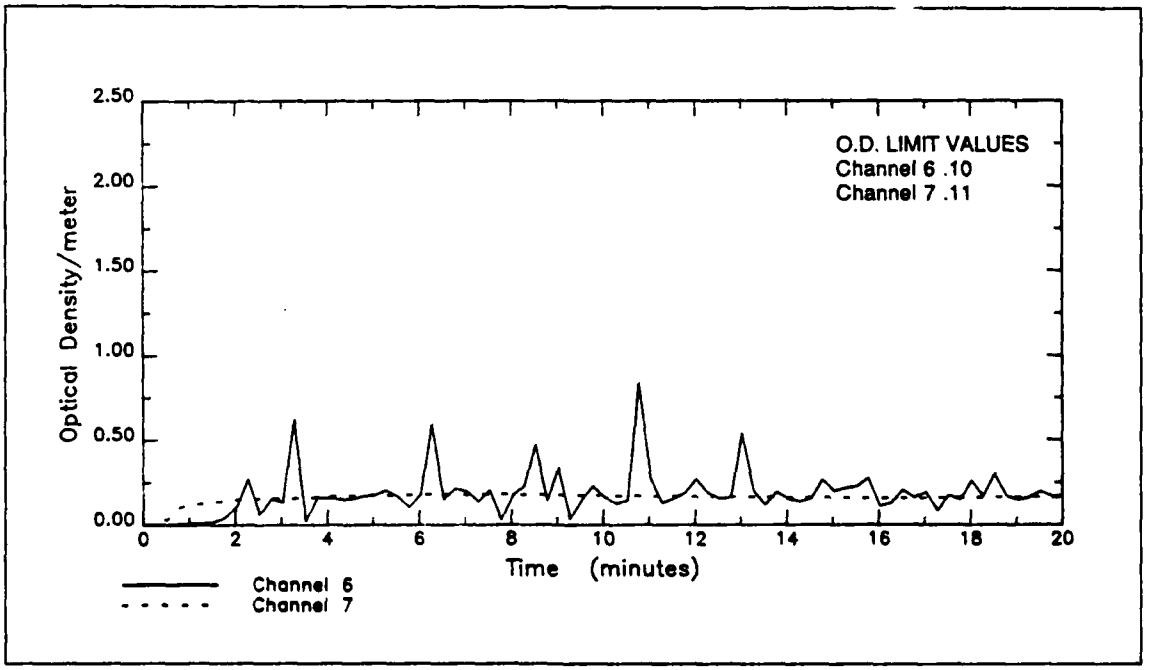



FIGURE B 16-1. Weight of Carbon Dioxide vs Time

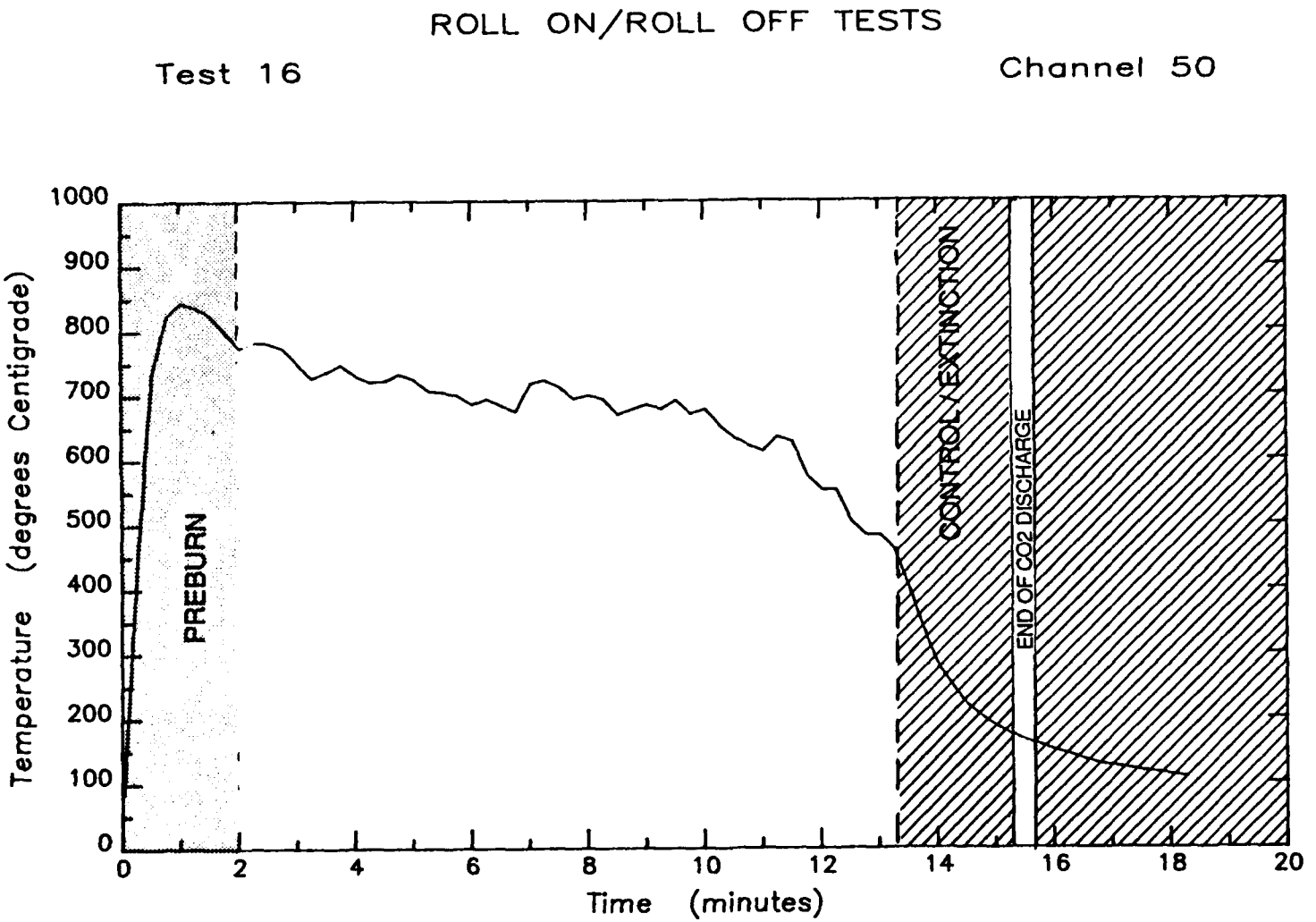



a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 16-2. OPTICAL DENSITY vs TIME**




B 16-3

FIGURE B 16-3. Temperature vs Time - Location 9A

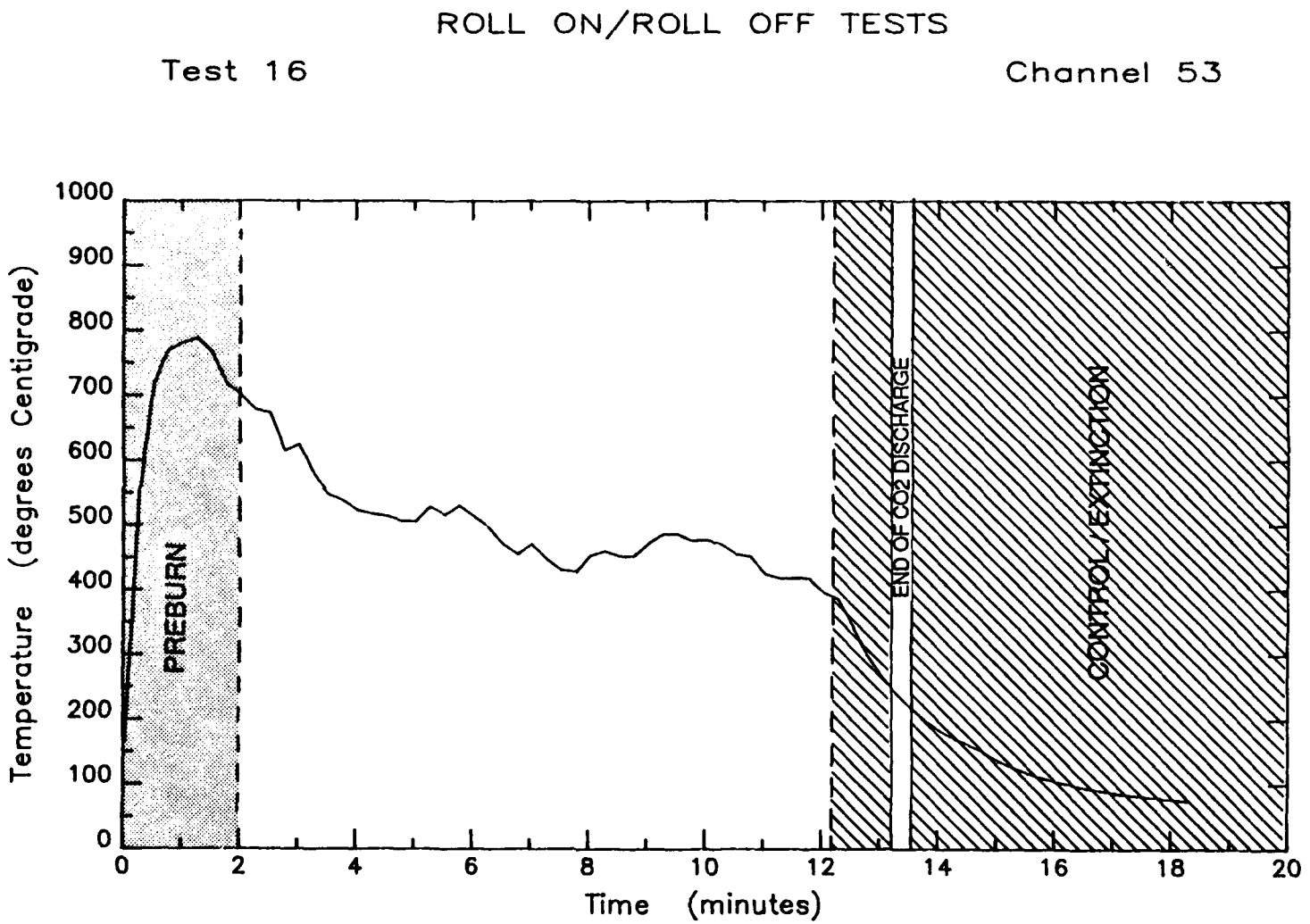


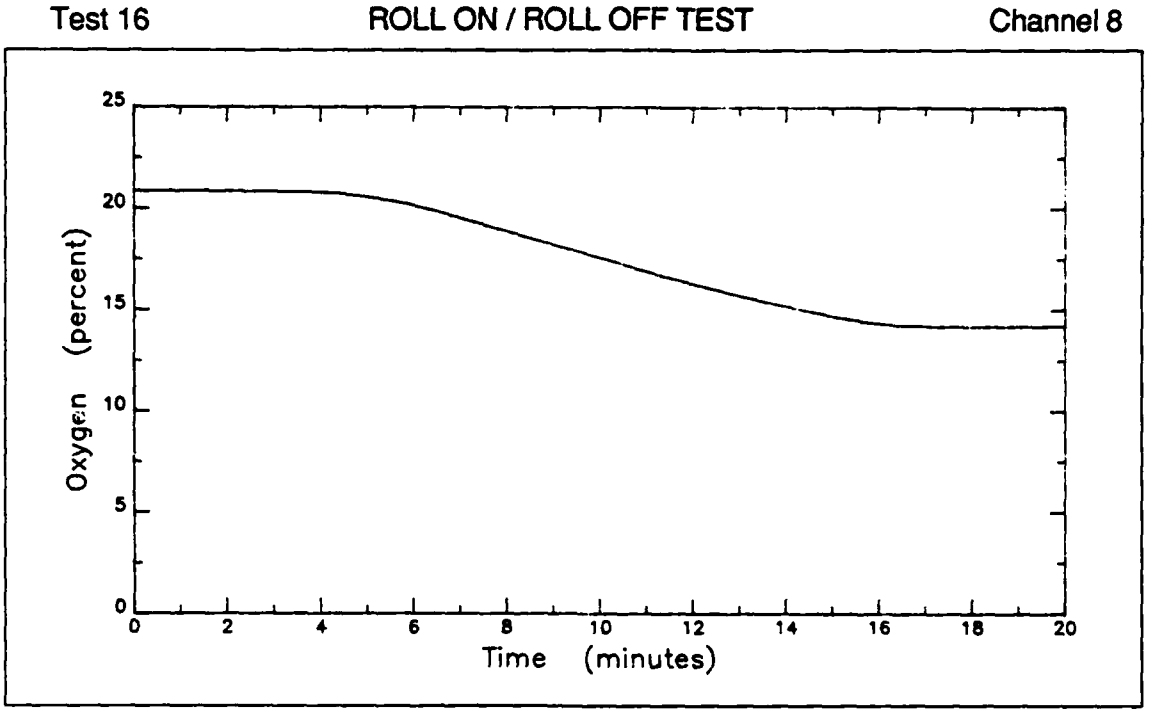

FIGURE B 16-4. Temperature vs Time - Location 10A

TEST 16

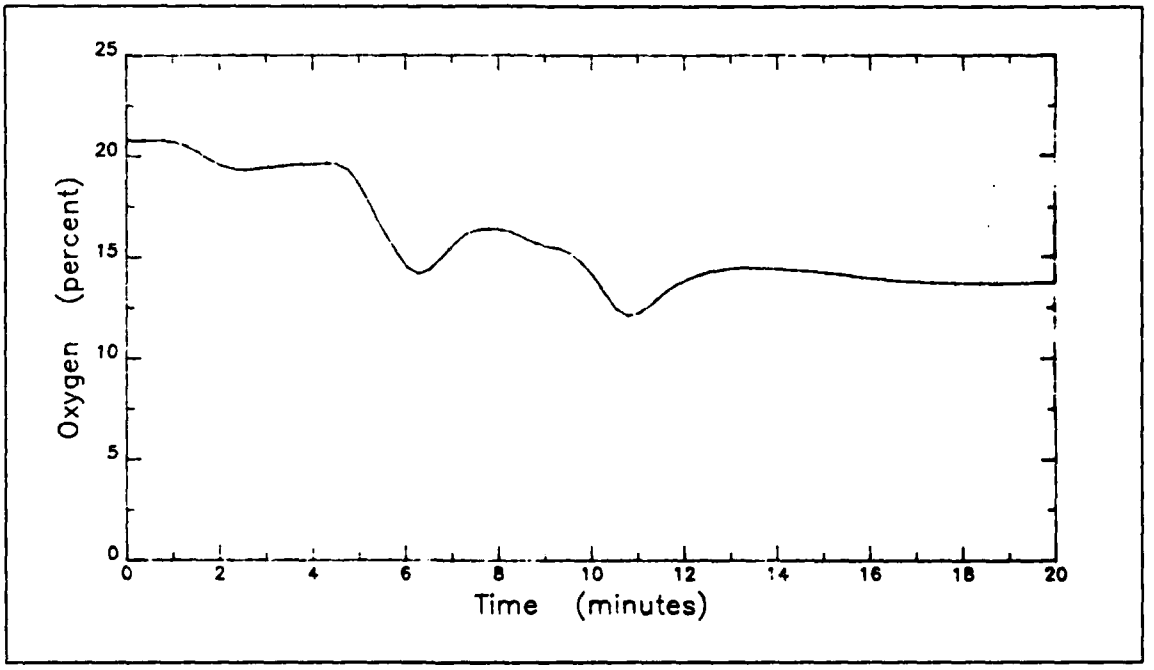
| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 12.8 | 15.7 | 17.8 | 14.2 | 14.4% OXYGEN @ 15.8 MINUTES |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 12.8 | 16.4 | 18.5 | 14.2 | 14.4% OXYGEN @ 16.4 MINUTES |
| 11 | Auto 11A | 12.8 | 16.1 | 15.3 | 15.4 | |
| 12 | Auto 9B | 12.8 | 15.3 | 14.0 | 15.0 | |
| 13 | Auto 12B | 12.8 | 16.8 | 15.5 | 16.5 | |
| | | AVERAGE | 16.1 | 16.0 | 15.1 | |



FIGURE B 16-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

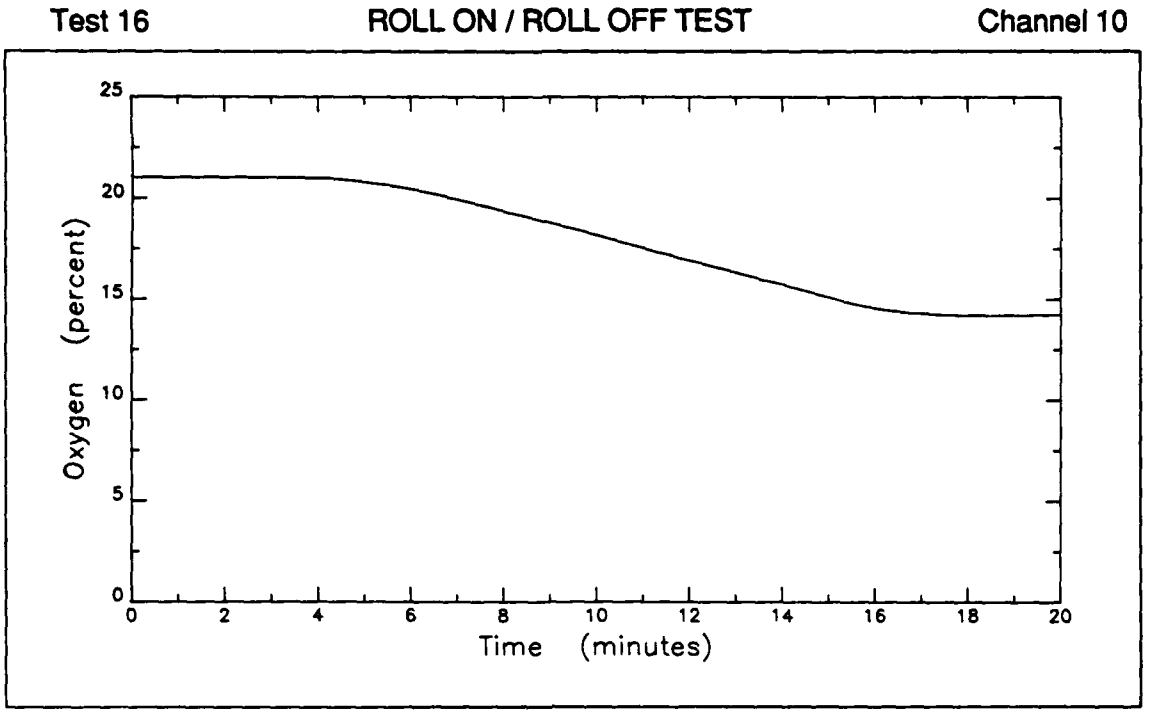



a. Test location - Automobile 9A

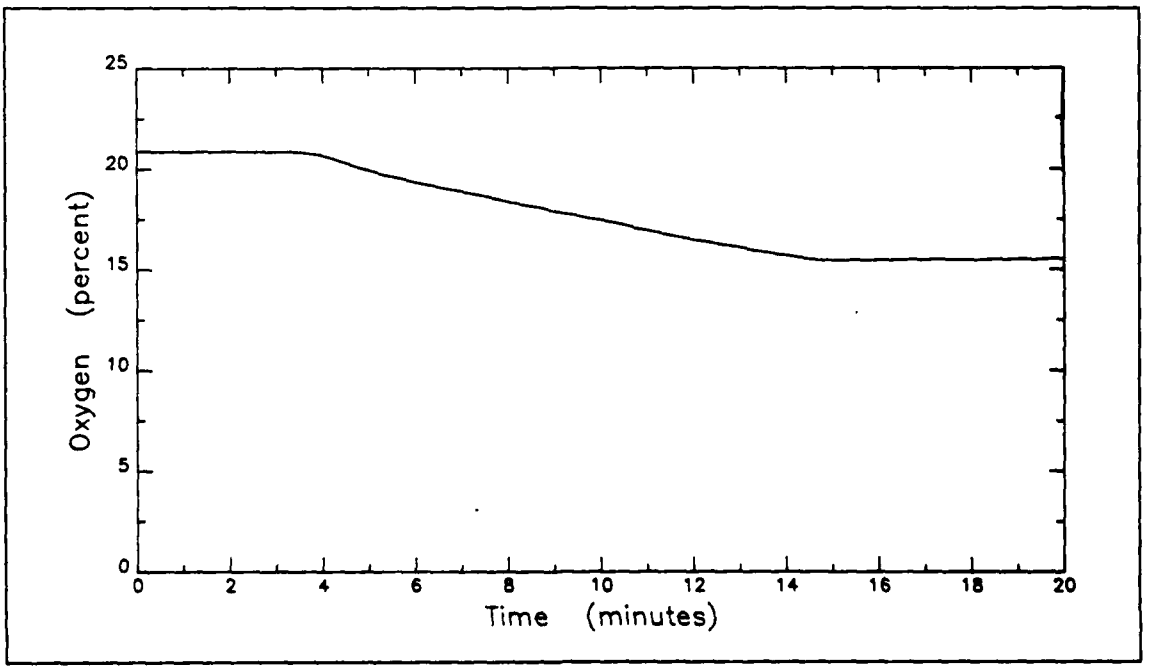



b. Test location - Automobile 10A

**FIGURE B 16-6. PERCENT OXYGEN vs TIME**

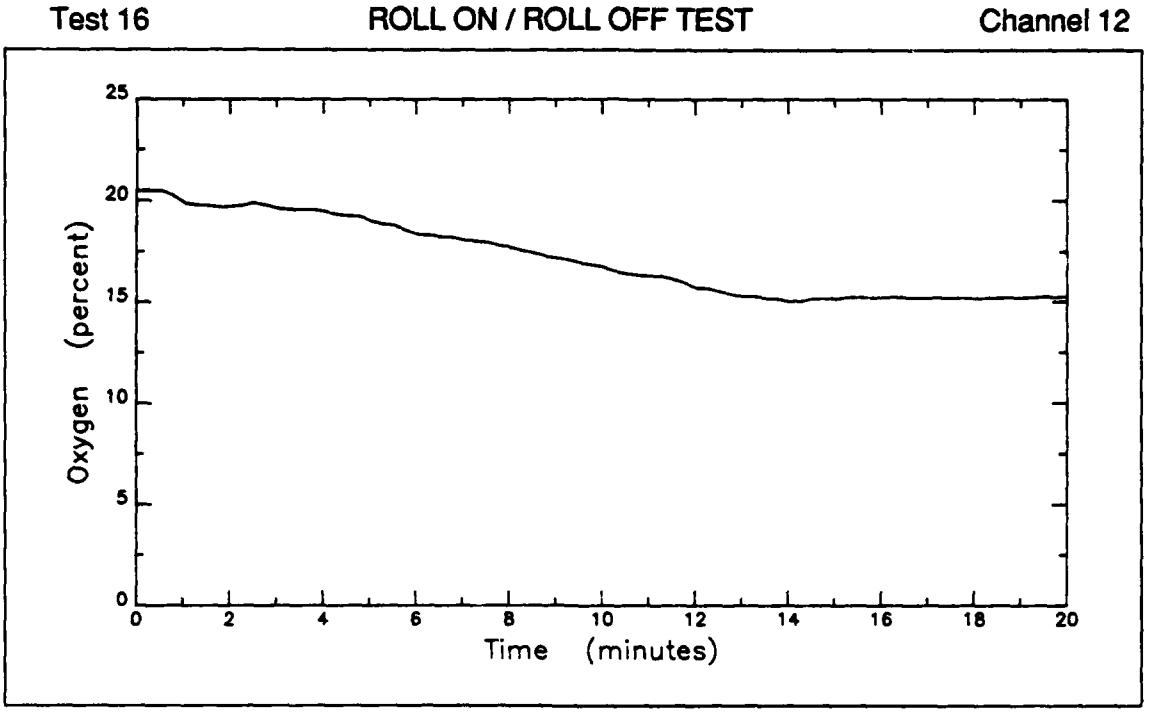



c. Test location - Automobile 11A

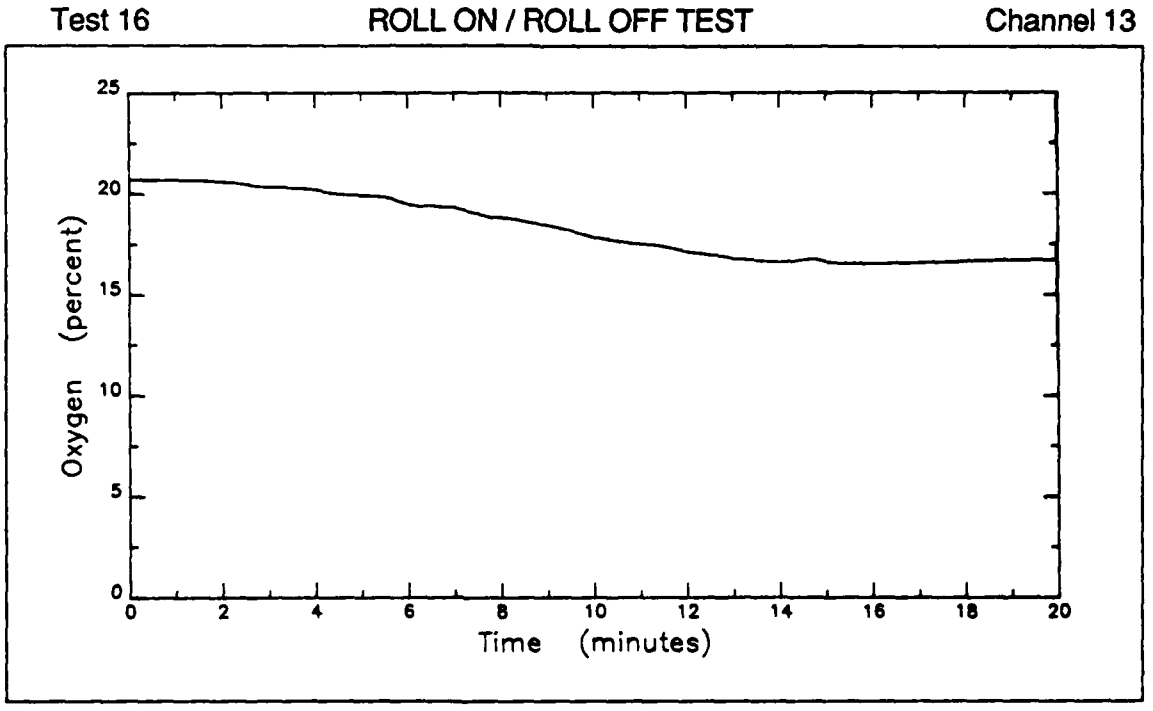



d. Test location - Automobile 12A

**FIGURE B 16-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B



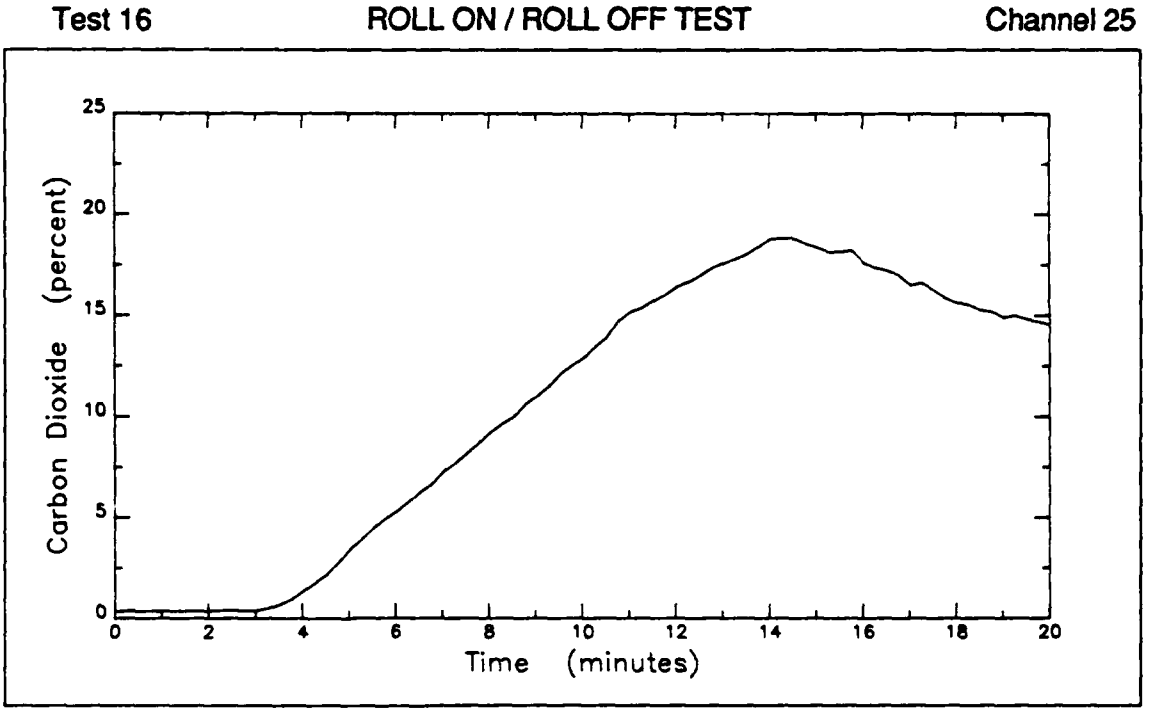

f. Test location - Automobile 12A

**FIGURE B 16-6. PERCENT OXYGEN vs TIME (cont'd)**

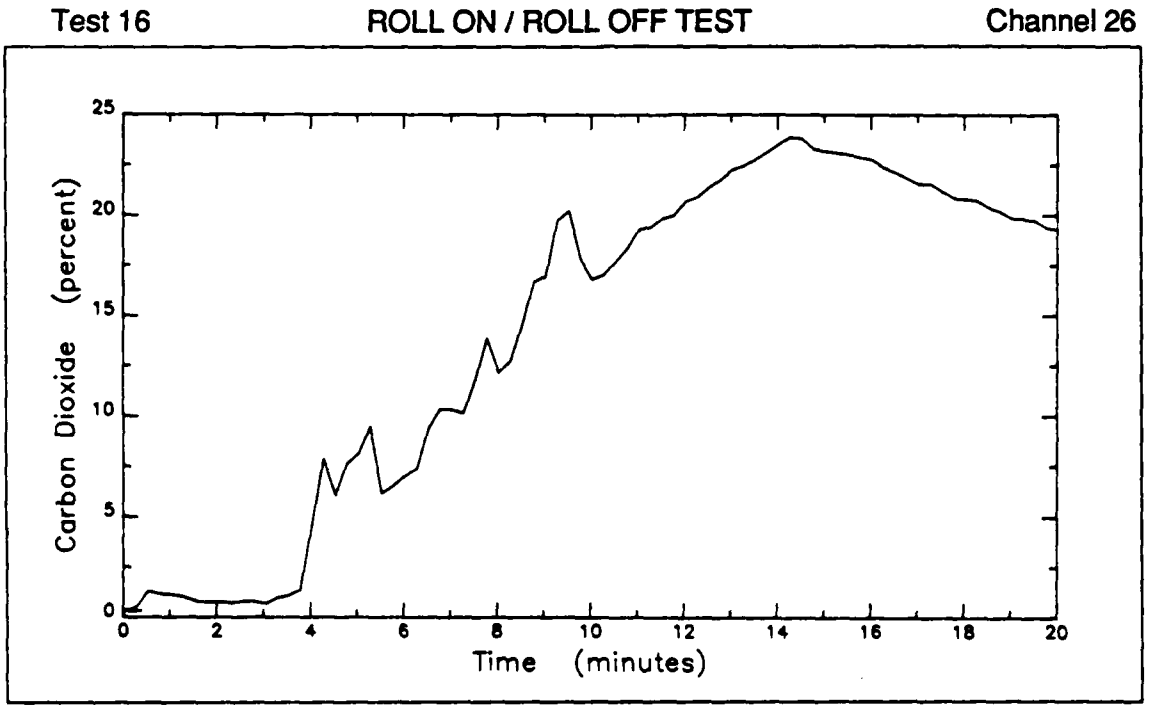
TEST 16

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 12.8 | 17.4 | 14.3 | 18.8 | |
| 26 | Auto 10A | 12.8 | 21.9 | 14.3 | 23.9 | |
| 27 | Auto 11A | 12.8 | 23.7 | 19.0 | 28.6 | |
| 28 | Auto 12A | 12.8 | 21.1 | 14.0 | 24.2 | |
| 29 | Auto 9C | 12.8 | 22.8 | 14.8 | 25.7 | |
| 30 | Auto 3A | 12.8 | 17.3 | 16.3 | 20.1 | |
| 31 | Auto 9B | 12.8 | 27.4 | 18.5 | 31.6 | |
| 32 | Auto 12B | 12.8 | 27.7 | 20.0 | 31.9 | |
| 33 | Auto 3B | 12.8 | 20.2 | 14.8 | 23.6 | |
| | | AVERAGE | 22.2 | 15.8 | 24.6 | |

FIGURE B 16-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

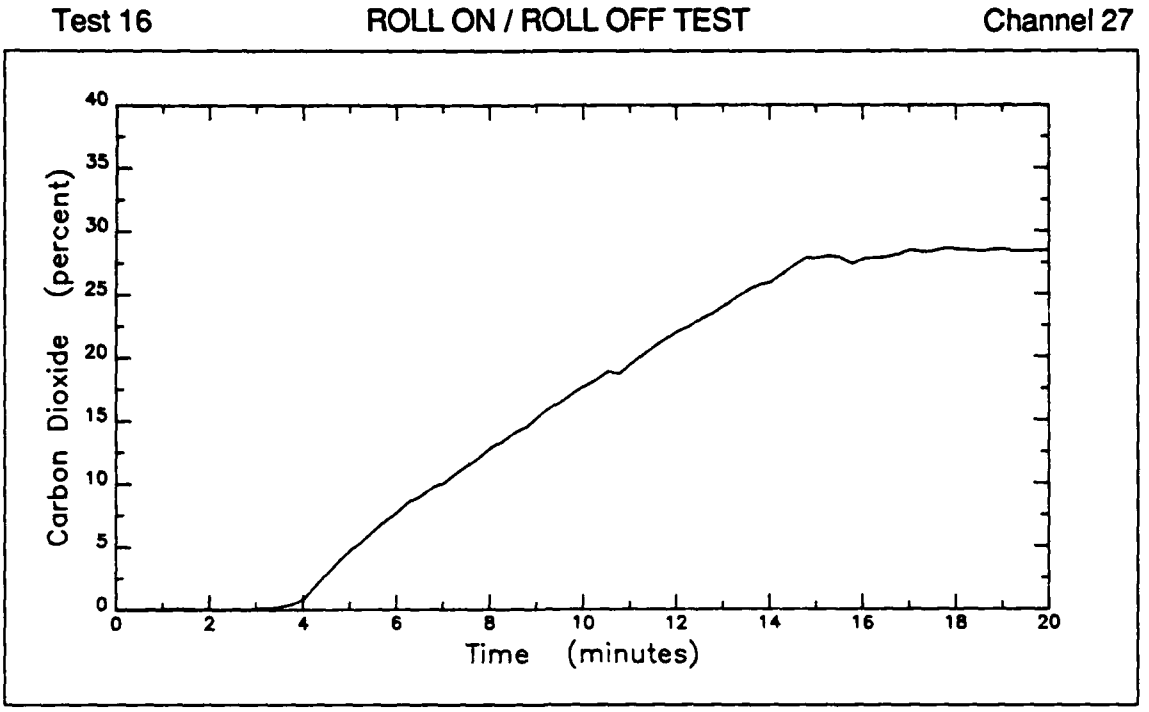



a. Test location - Automobile 9A

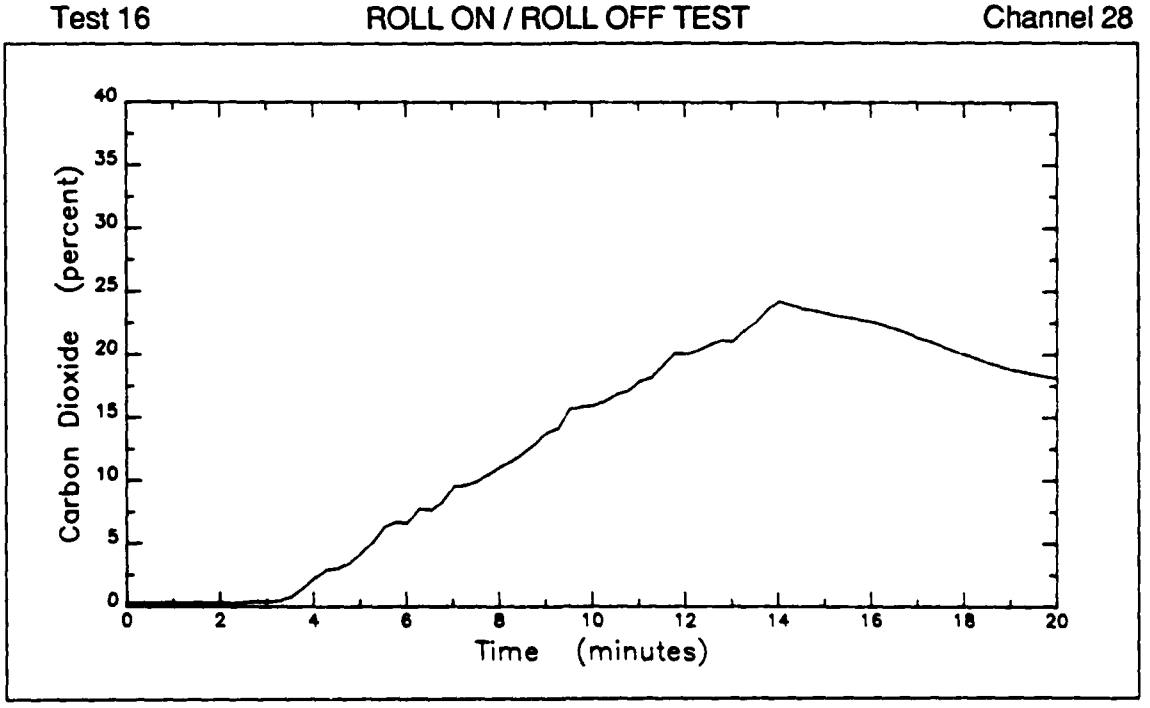



b. Test location - Automobile 10A

**FIGURE B 16-8. PERCENT CARBON DIOXIDE vs TIME**

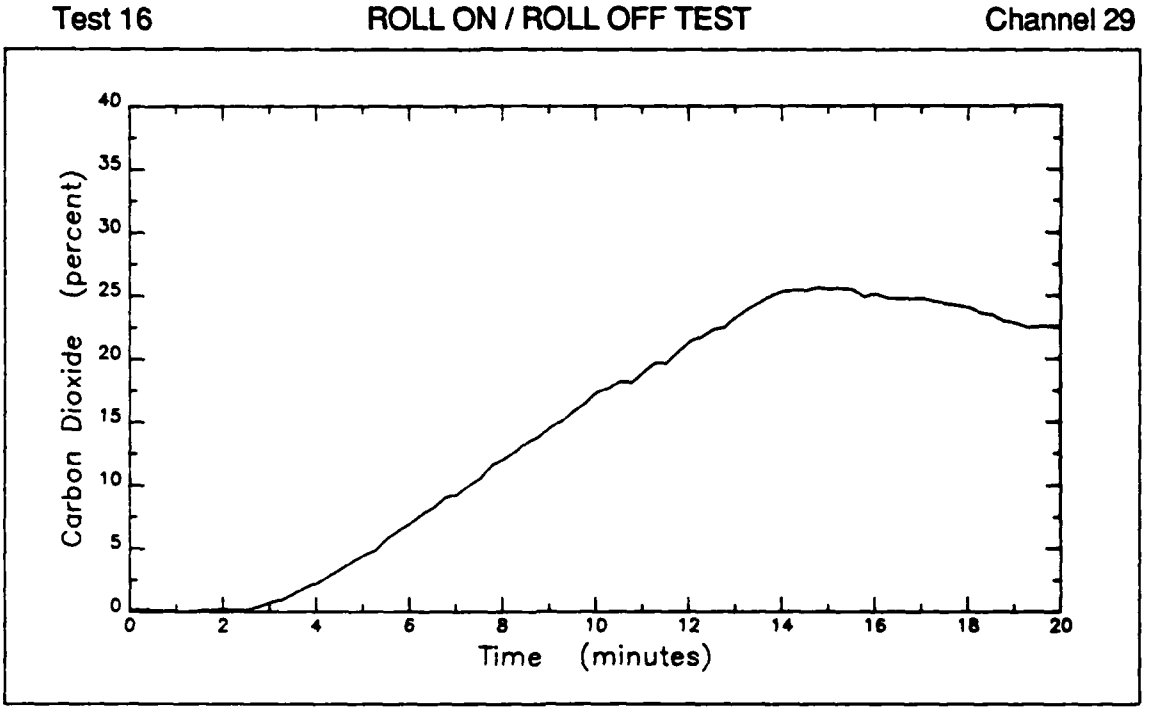



c. Test location - Automobile 11A

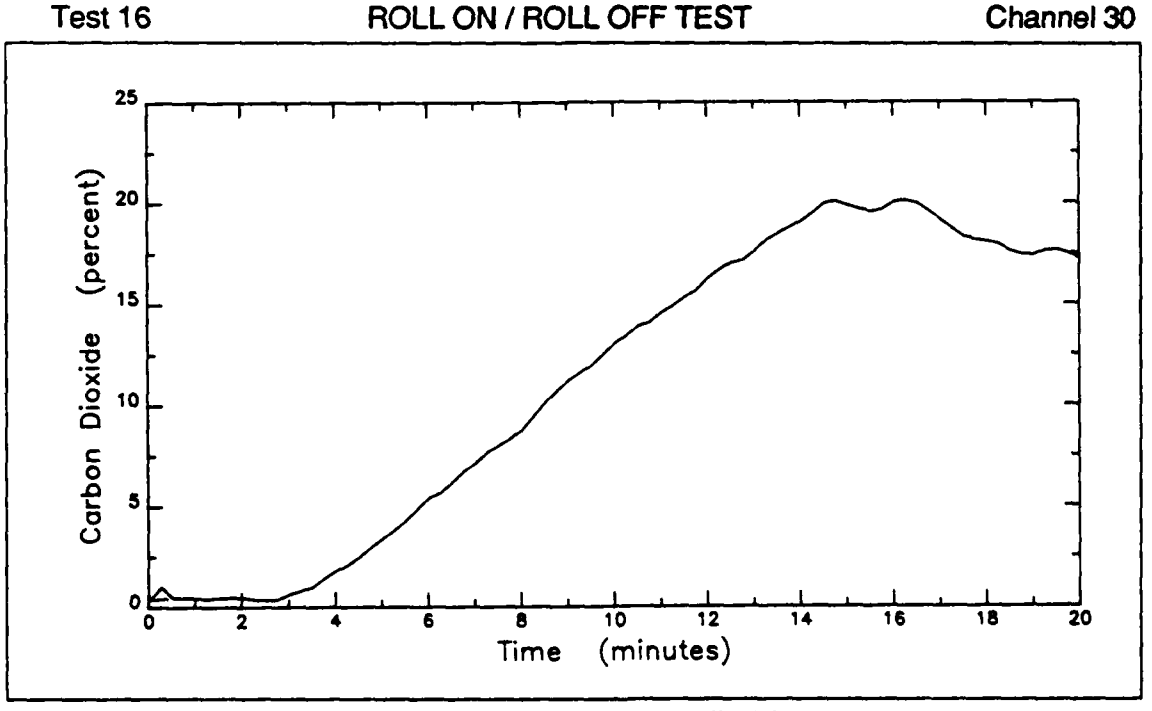



d. Test location - Automobile 12A

**FIGURE B 16-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

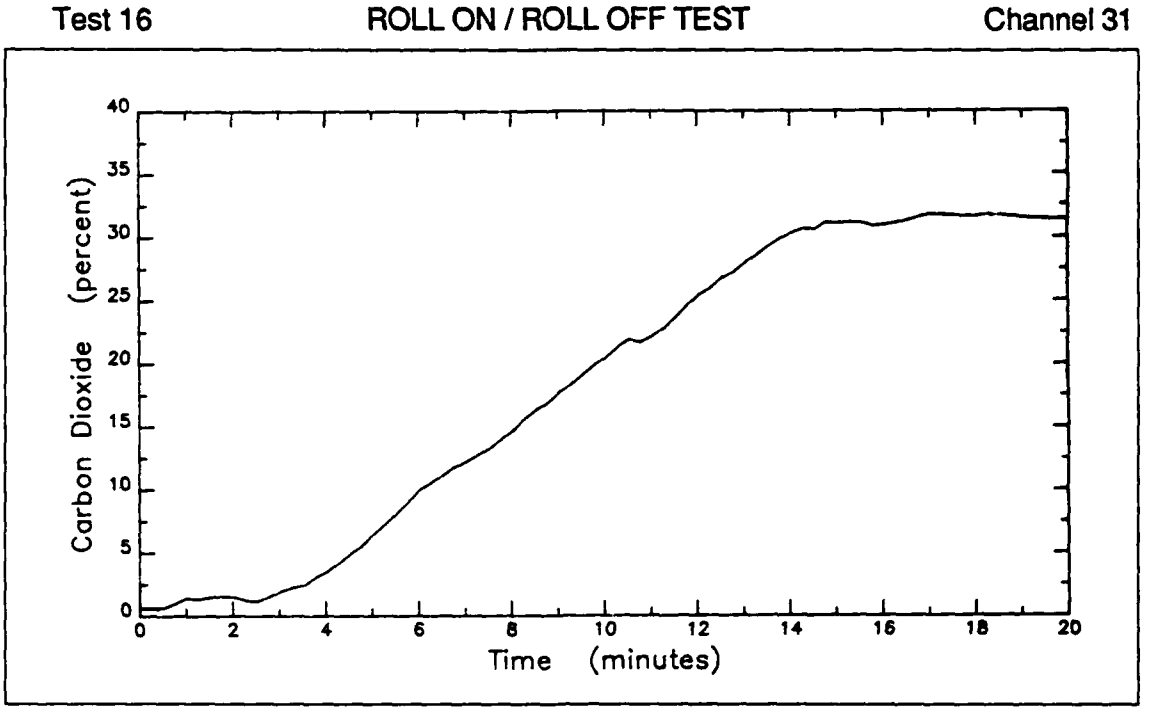



e. Test location - Automobile 9C

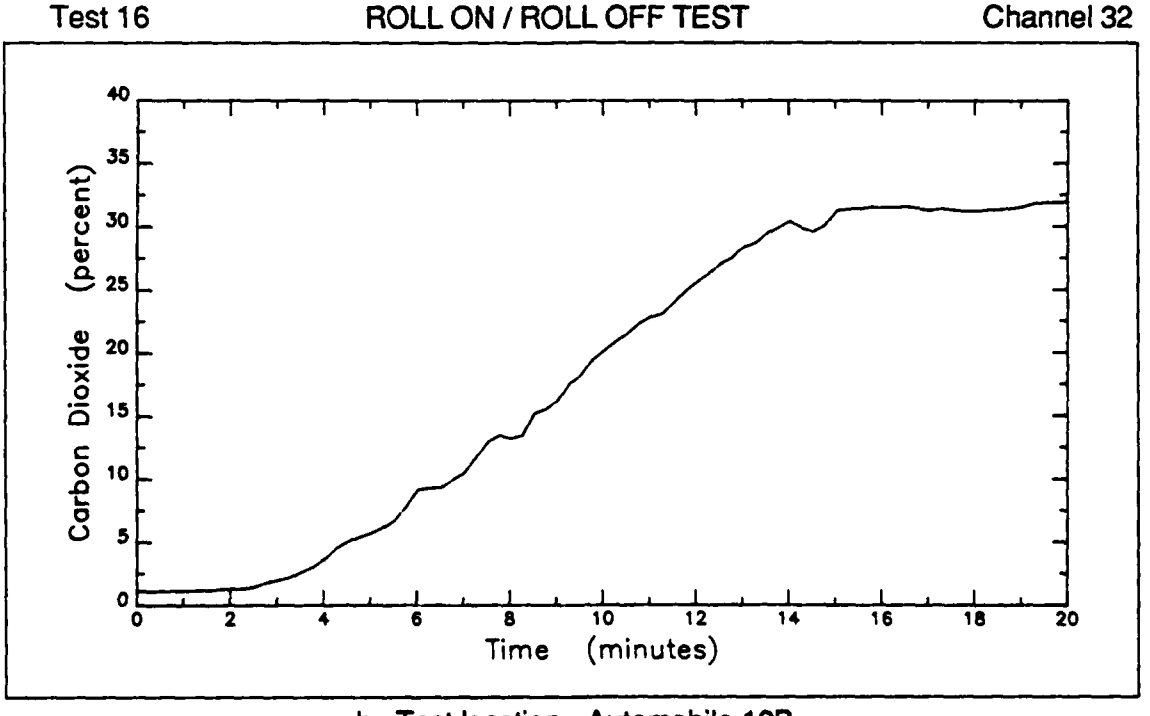



f. Test location - Automobile 3A

**FIGURE B 16-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

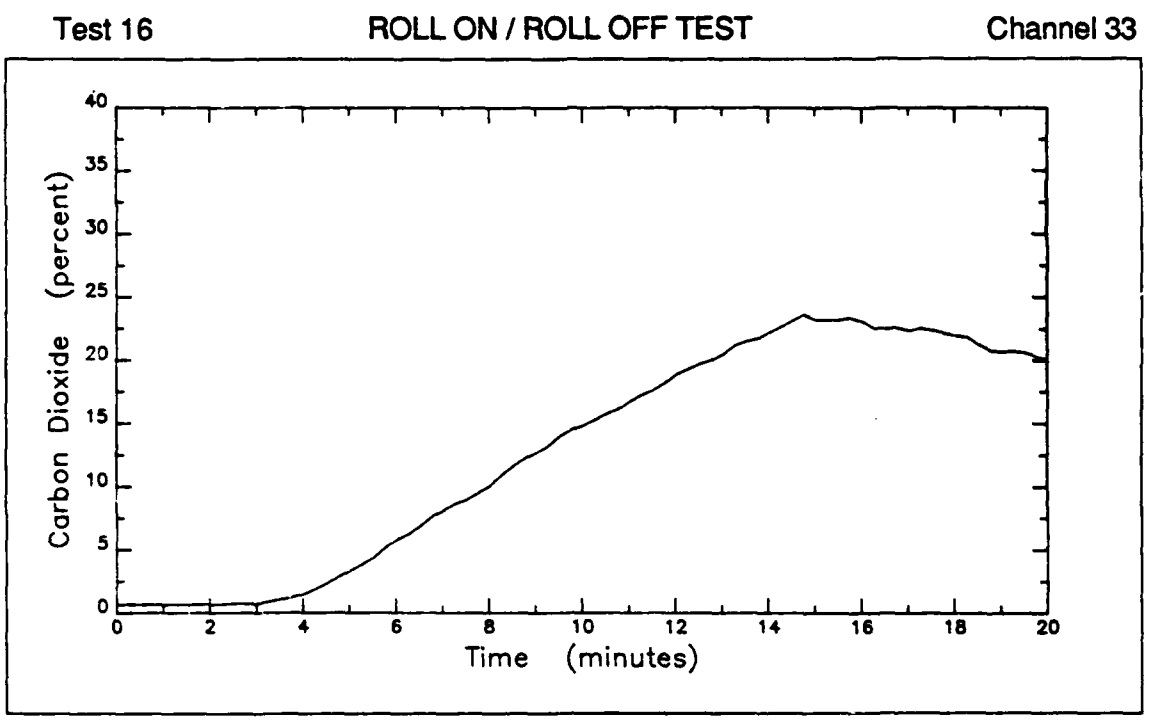



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 16-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

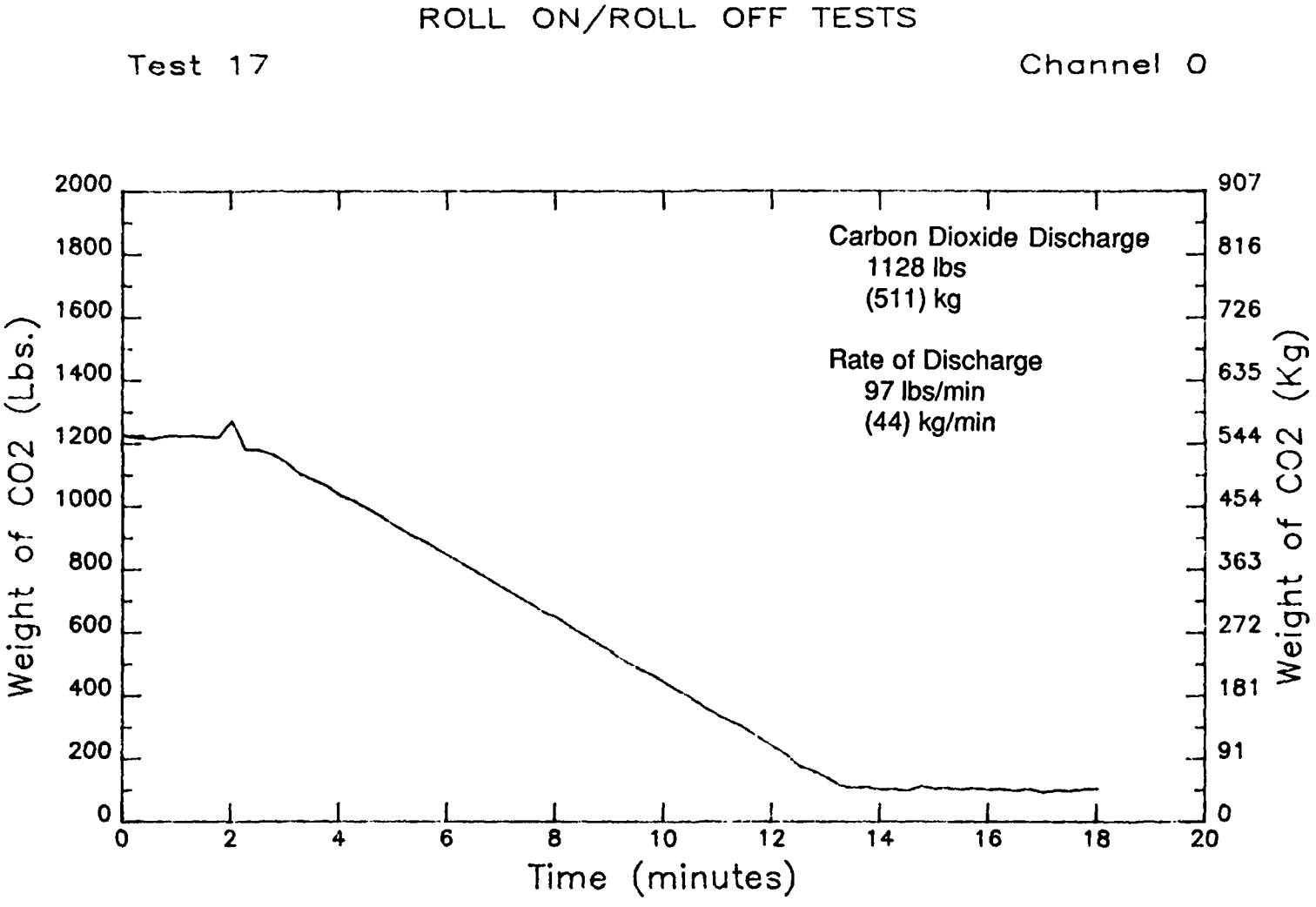



i. Test location - Automobile 3B

**FIGURE B 16-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

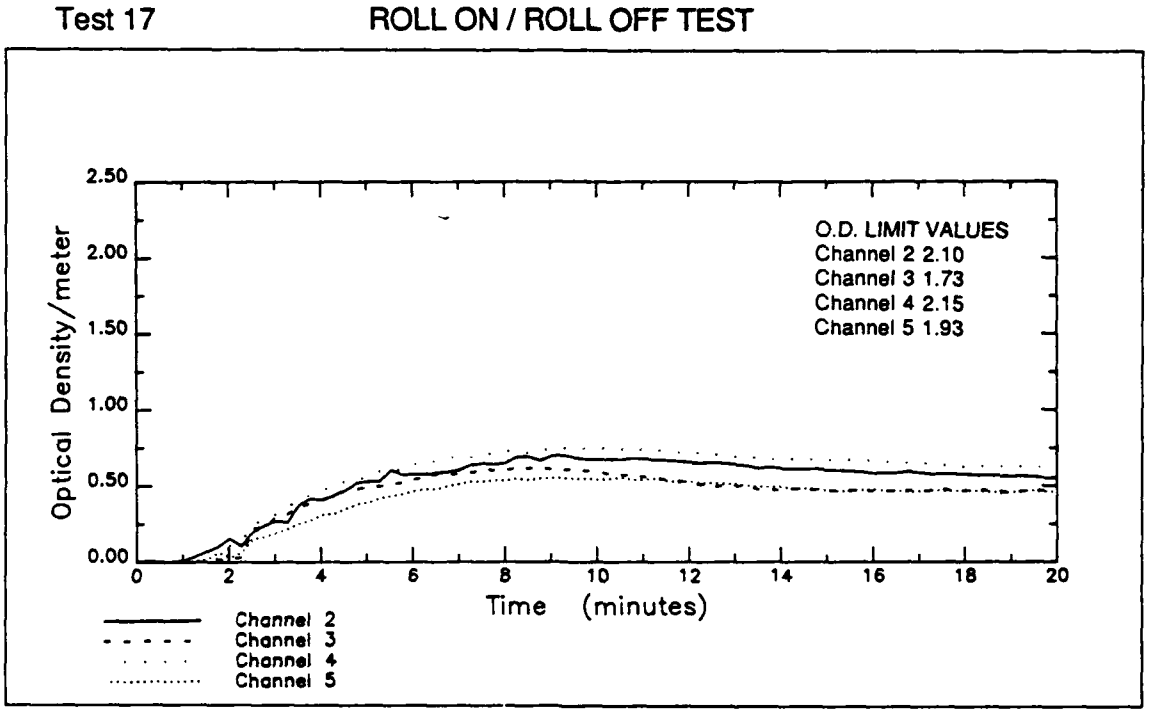
# APPENDIX B

# TEST 17

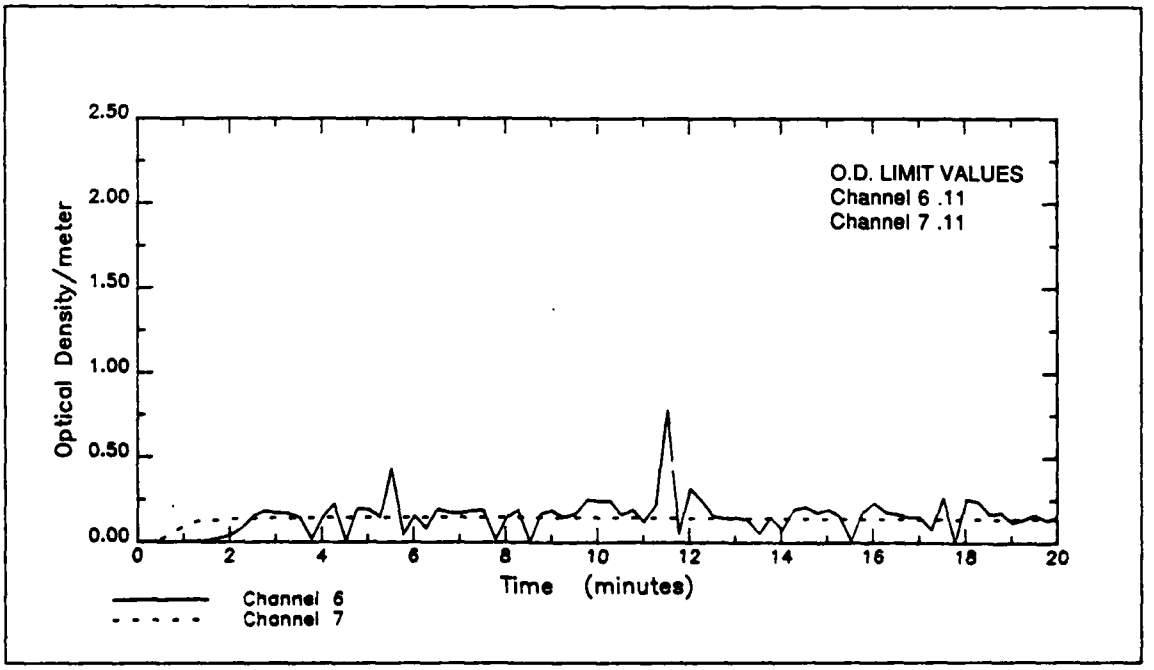



B17-1

FIGURE B 17-1. Weight of Carbon Dioxide vs Time




a. Data Channels 2,3,4,5




b. Data Channels 6, 7

**FIGURE 17-2. OPTICAL DENSITY vs TIME**

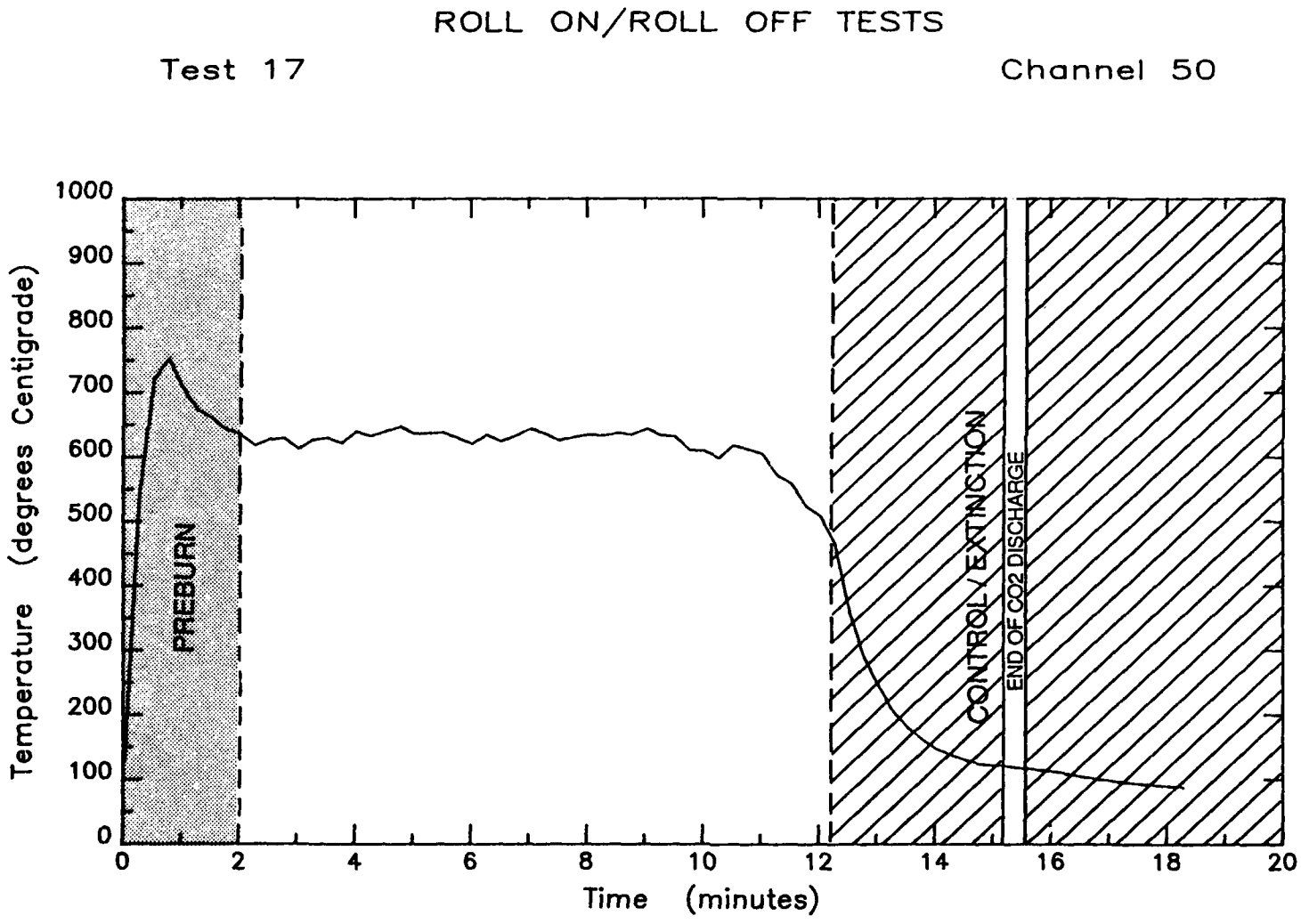
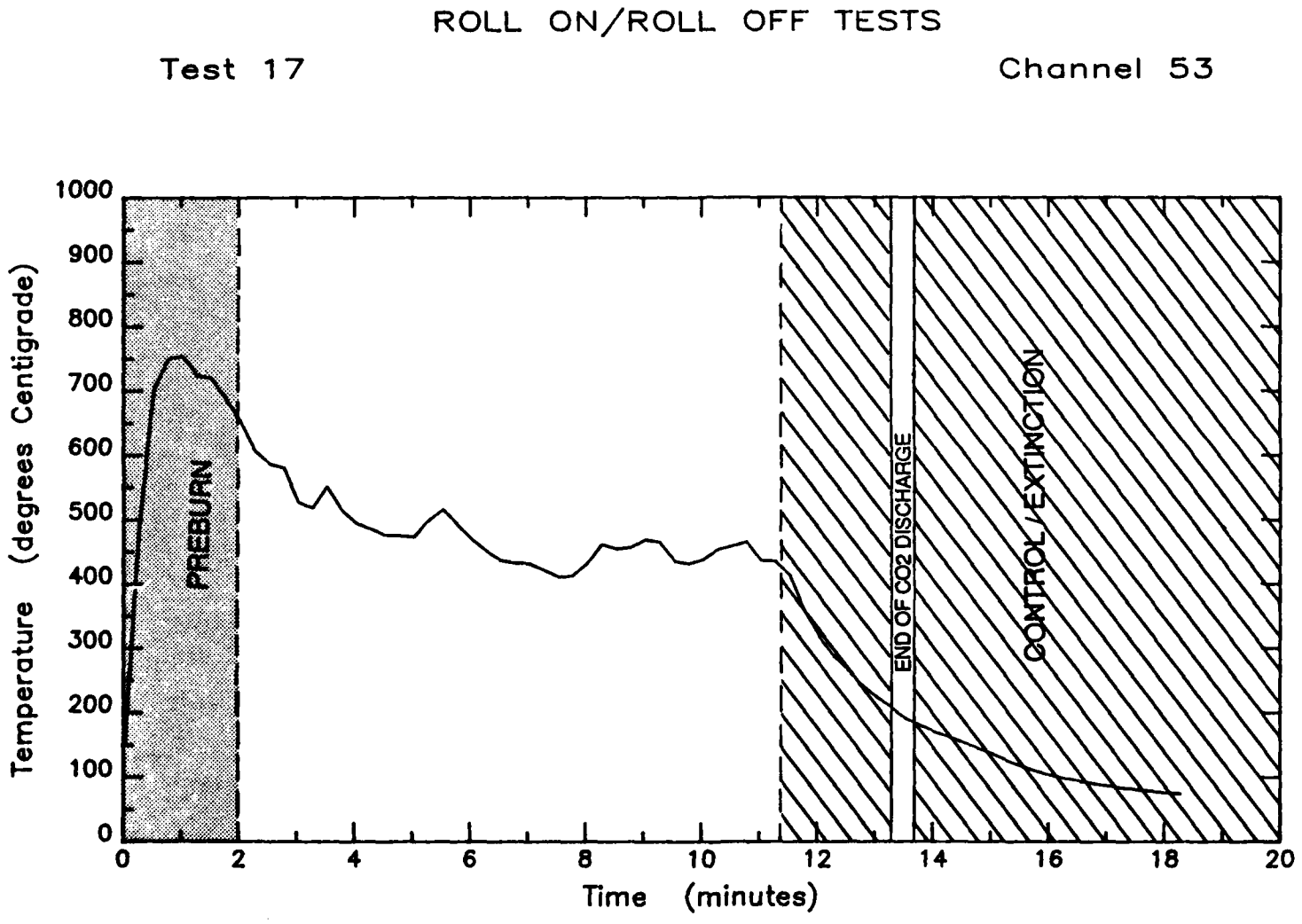



FIGURE B 17-3. Temperature vs Time - Location 9A



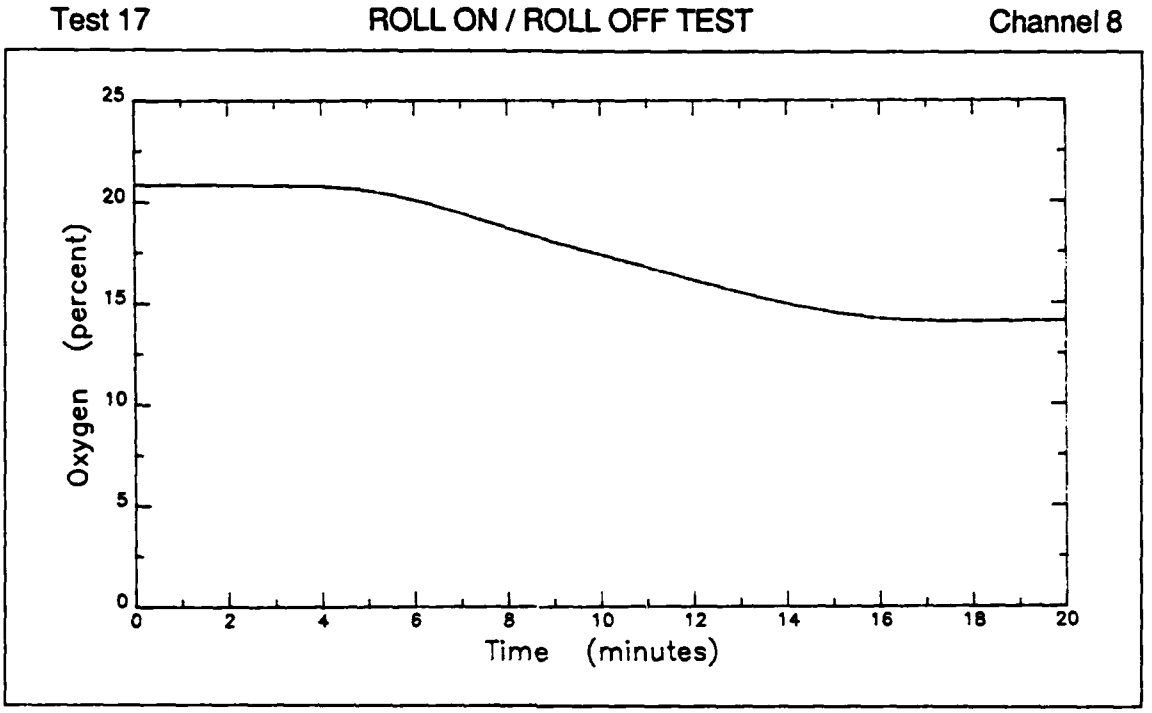

B17-4

FIGURE B 17-4. Temperature vs Time - Location 10A

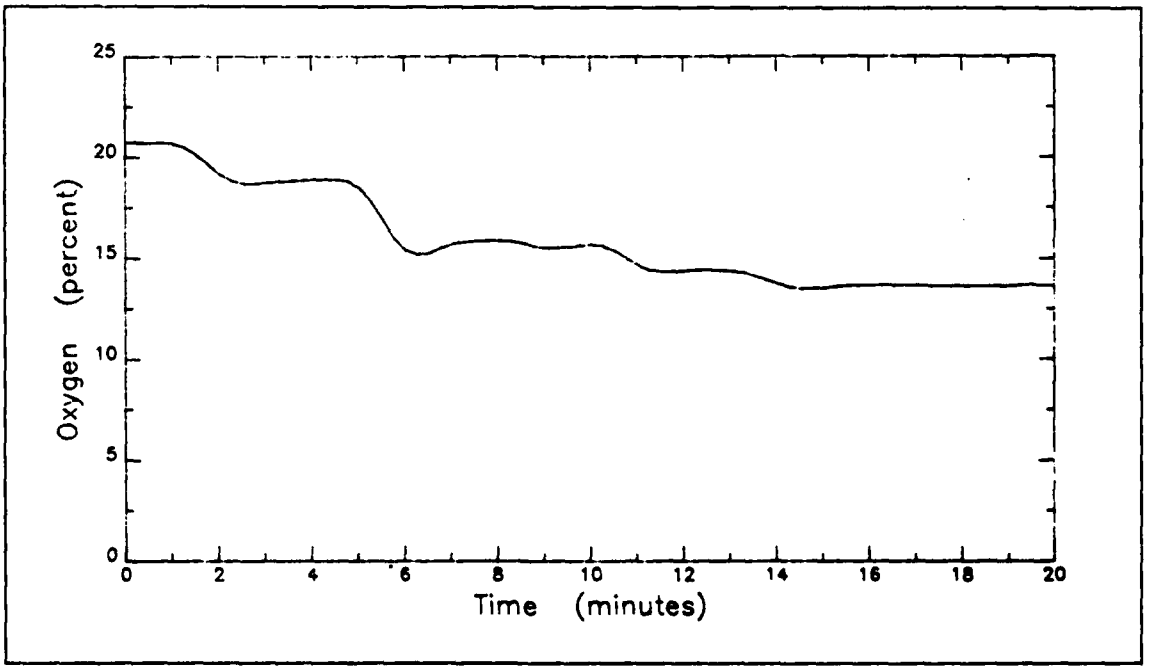
TEST 17

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME OXYGEN (%) | MINIMUM O2 TIME (MINUTES) | MINIMUM O2 OXYGEN (%) | REMARKS |
|---|---|---|---|---|---|---|
| 8 | Auto 9A | 12.0 | 16.2 | 17.8 | 14.1 | 14.4% OXYGEN @ 15.3 MINUTES |
| 9 | Auto 10A | -- | -- | -- | -- | |
| 10 | Auto 12A | 12.0 | 16.8 | 19.0 | 14.1 | 14.4% OXYGEN @ 16.1 MINUTES |
| 11 | Auto 11A | 12.0 | 16.5 | 14.8 | 15.4 | |
| 12 | Auto 9B | 12.0 | 15.7 | 15.2 | 15.1 | |
| 13 | Auto 12B | 12.0 | 17.1 | 15.0 | 16.4 | |
| | | AVERAGE | 16.5 | 16.4 | 15.0 | |

FIGURE B 17-5. Percent Oxygen at Onset of Fire Control and Minimum Percent Oxygen During Test

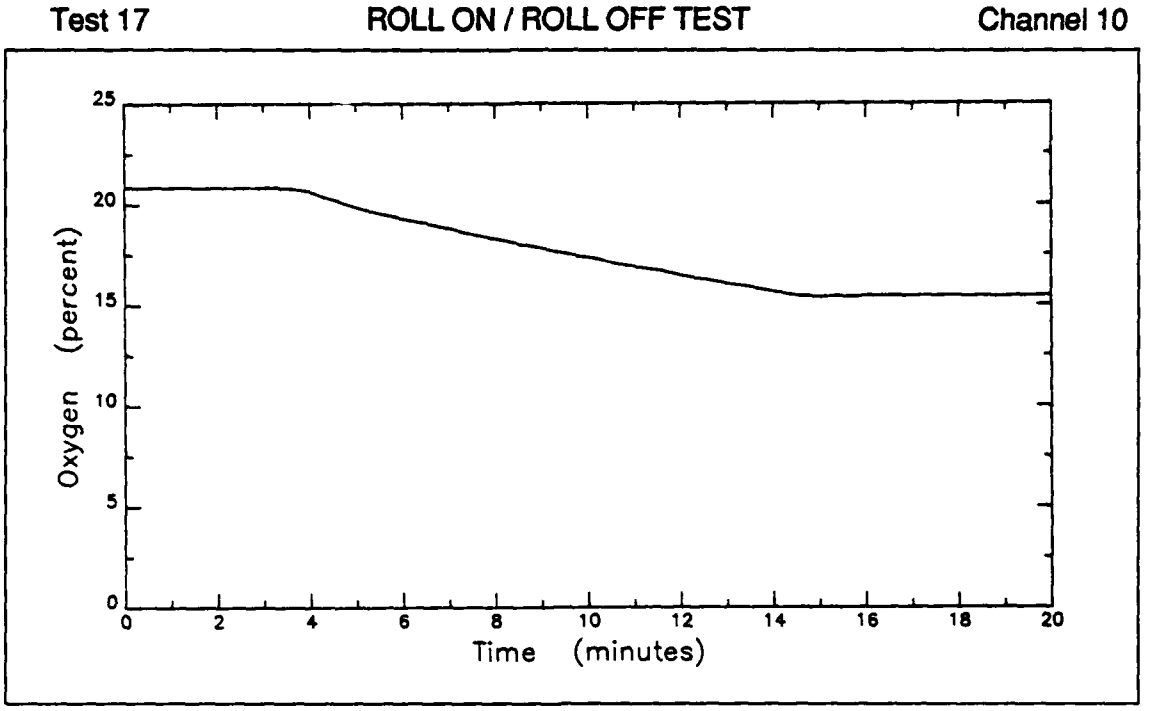



a. Test location - Automobile 9A

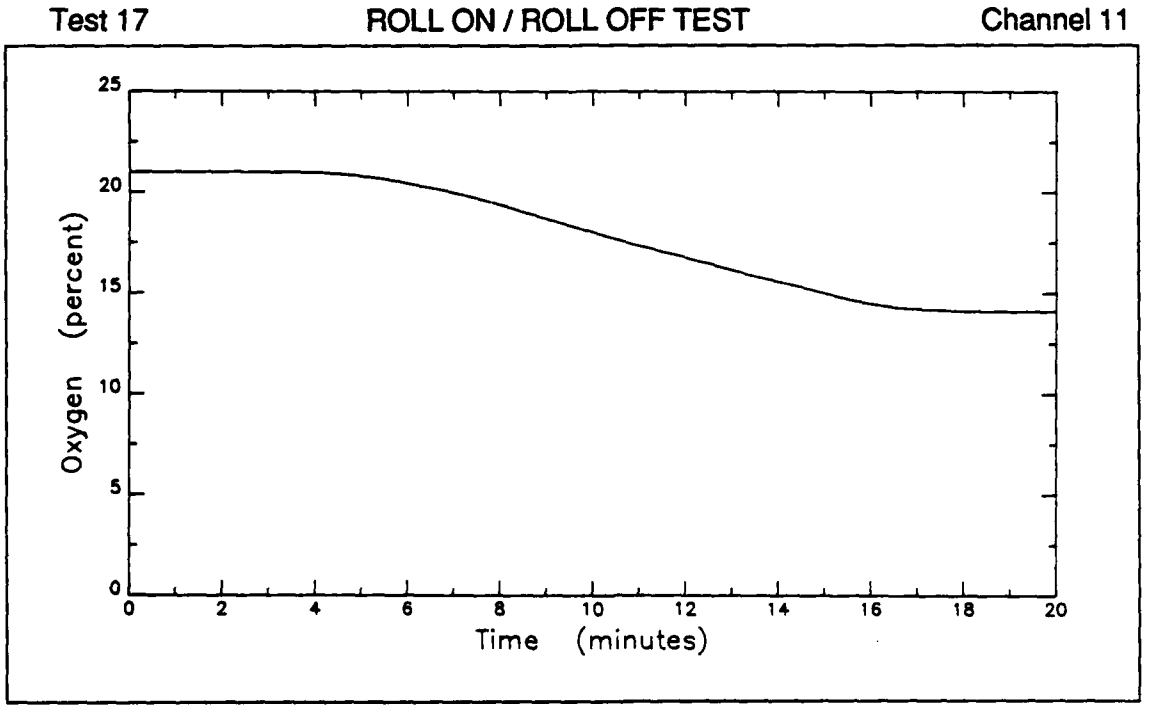



b. Test location - Automobile 10A

**FIGURE B 17-6. PERCENT OXYGEN vs TIME**

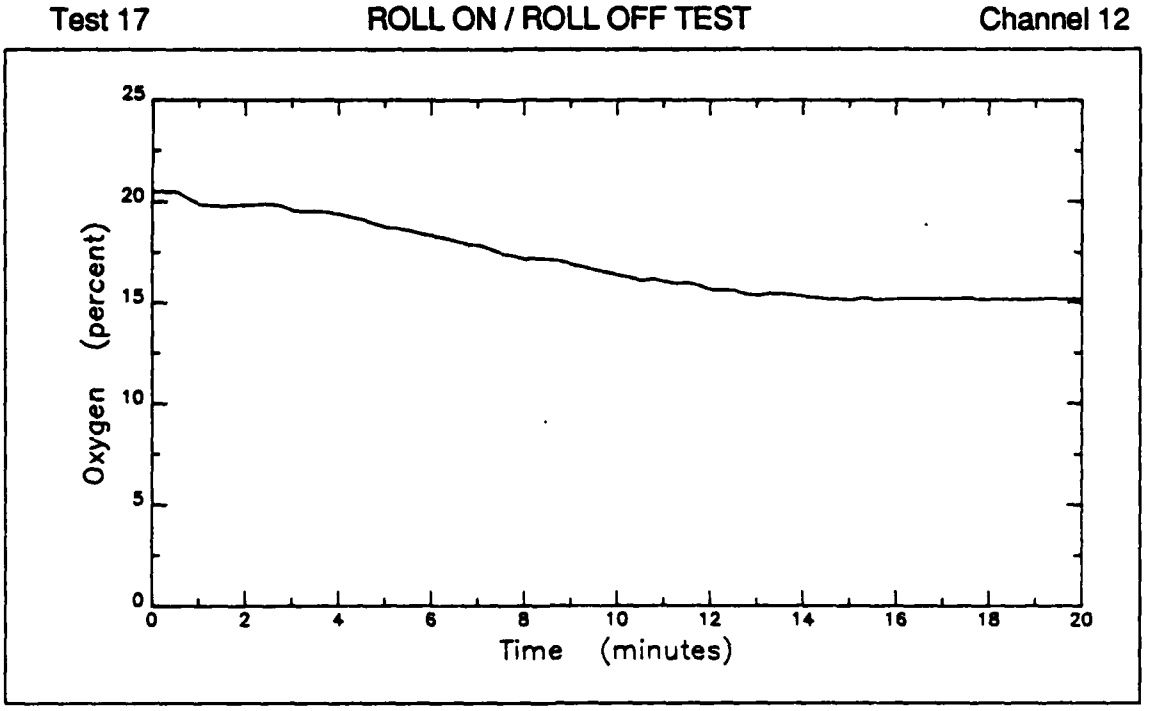



c. Test location - Automobile 11A

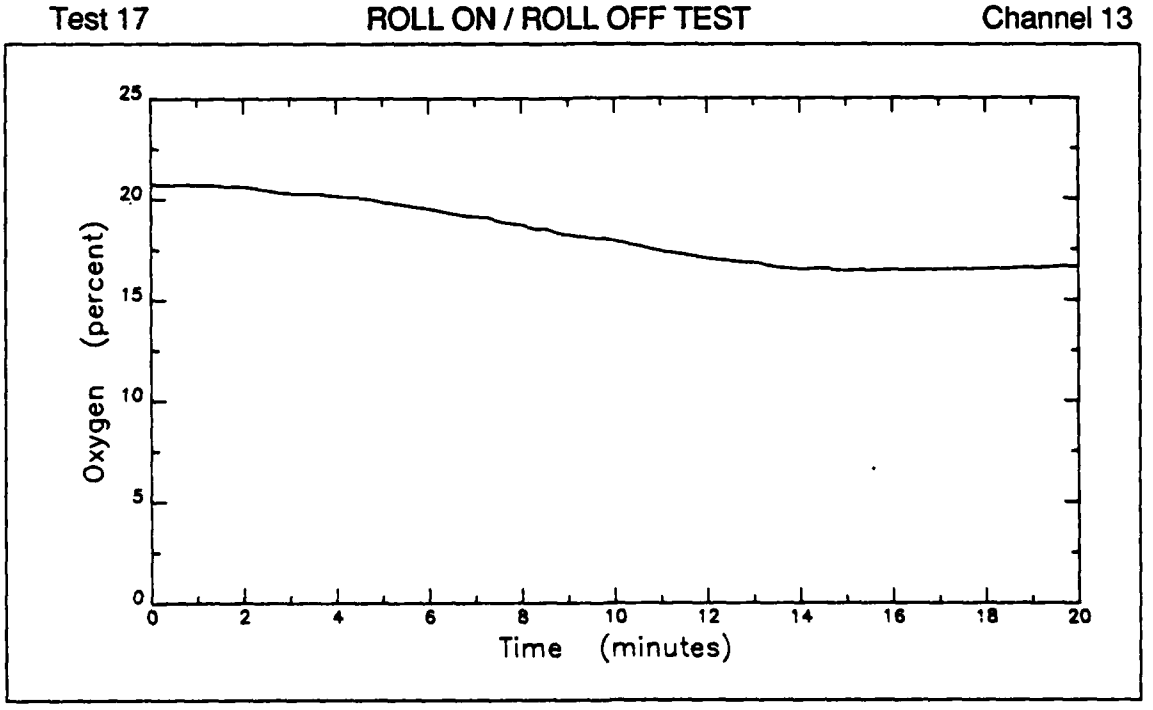



d. Test location - Automobile 12A

**FIGURE B 17-6. PERCENT OXYGEN vs TIME (cont'd)**




e. Test location - Automobile 9B



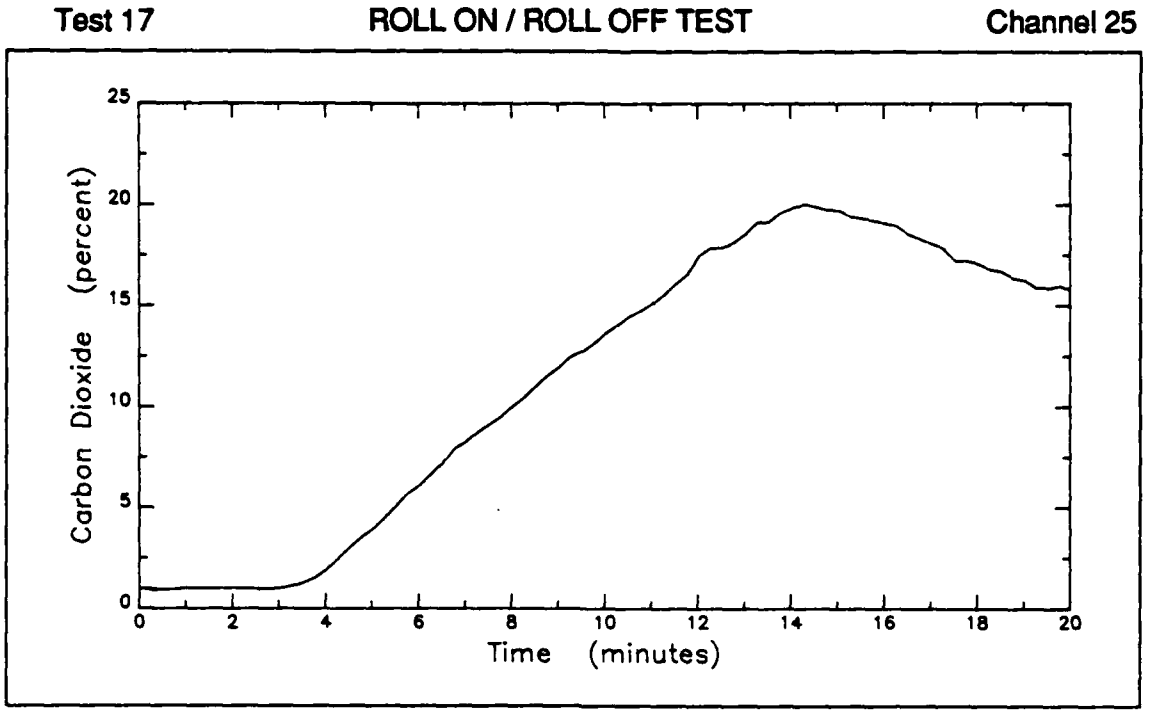

f. Test location - Automobile 12B

**FIGURE B 17-6. PERCENT OXYGEN vs TIME (cont'd)**

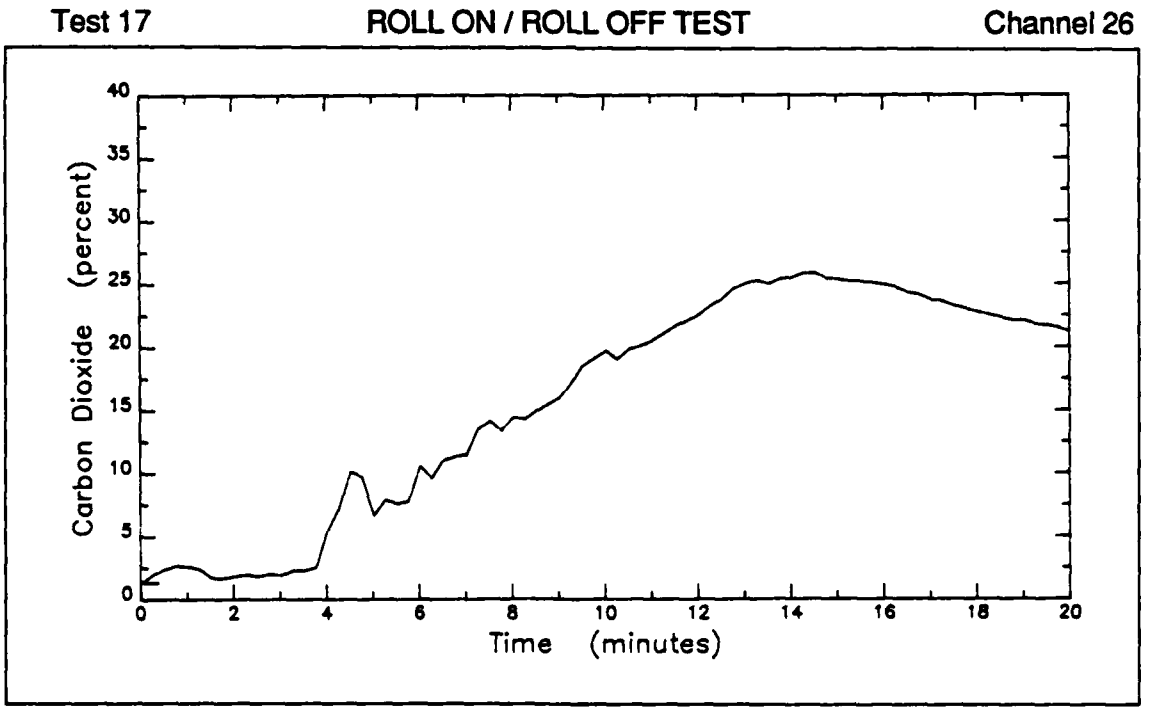
TEST 17

| CHANNEL | LOCATION | CONTROL TIME TIME (MINUTES) | CONTROL TIME CARBON DIOXIDE (%) | MAXIMUM CO2 TIME (MINUTES) | MAXIMUM CO2 CARBON DIOXIDE (%) | REMARKS |
|---|---|---|---|---|---|---|
| 25 | Auto 9A | 12.0 | 17.1 | 14.3 | 20.0 | |
| 26 | Auto 10A | 12.0 | 22.4 | 14.5 | 25.9 | |
| 27 | Auto 11A | 12.0 | 21.6 | 14.8 | 28.3 | |
| 28 | Auto 12A | 12.0 | 22.0 | 18.8 | 28.5 | |
| 29 | Auto 9C | 12.0 | 21.5 | 14.3 | 26.5 | |
| 30 | Auto 3A | 12.0 | 16.8 | 16.0 | 20.7 | |
| 31 | Auto 9B | 12.0 | 25.6 | 18.0 | 31.7 | |
| 32 | Auto 12B | 12.0 | 24.6 | 17.3 | 32.6 | |
| 33 | Auto 3B | 12.0 | 19.7 | 14.8 | 24.9 | |
| | | AVERAGE | 21.3 | 15.9 | 26.6 | |

FIGURE B 17-7. Percent Carbon Dioxide at Onset of Fire Control and Maximum Percent Carbon Dioxide During Test

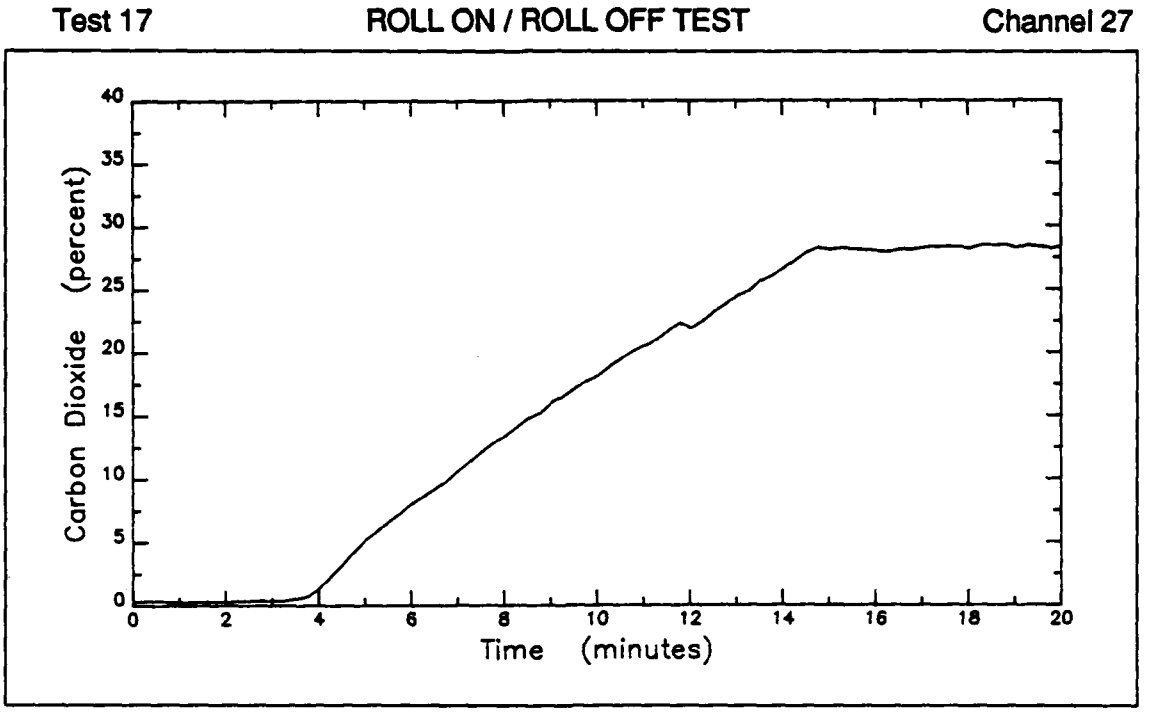



a. Test location - Automobile 9A

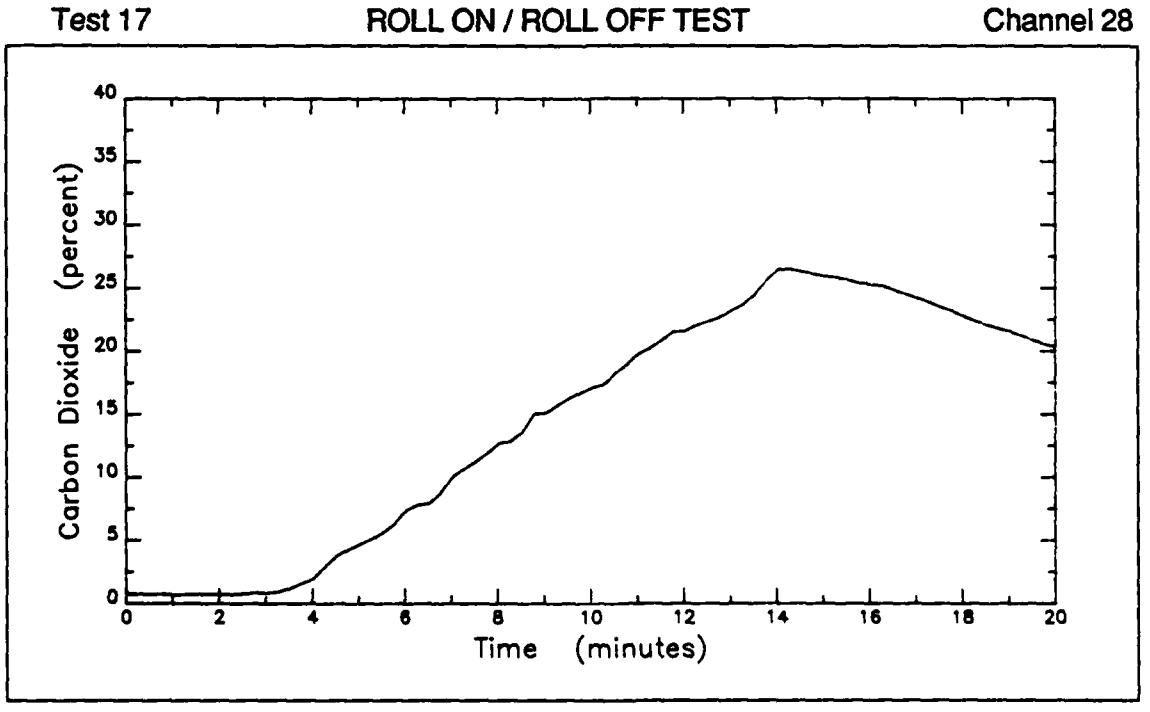



b. Test location - Automobile 10A

**FIGURE B 17-8. PERCENT CARBON DIOXIDE vs TIME**

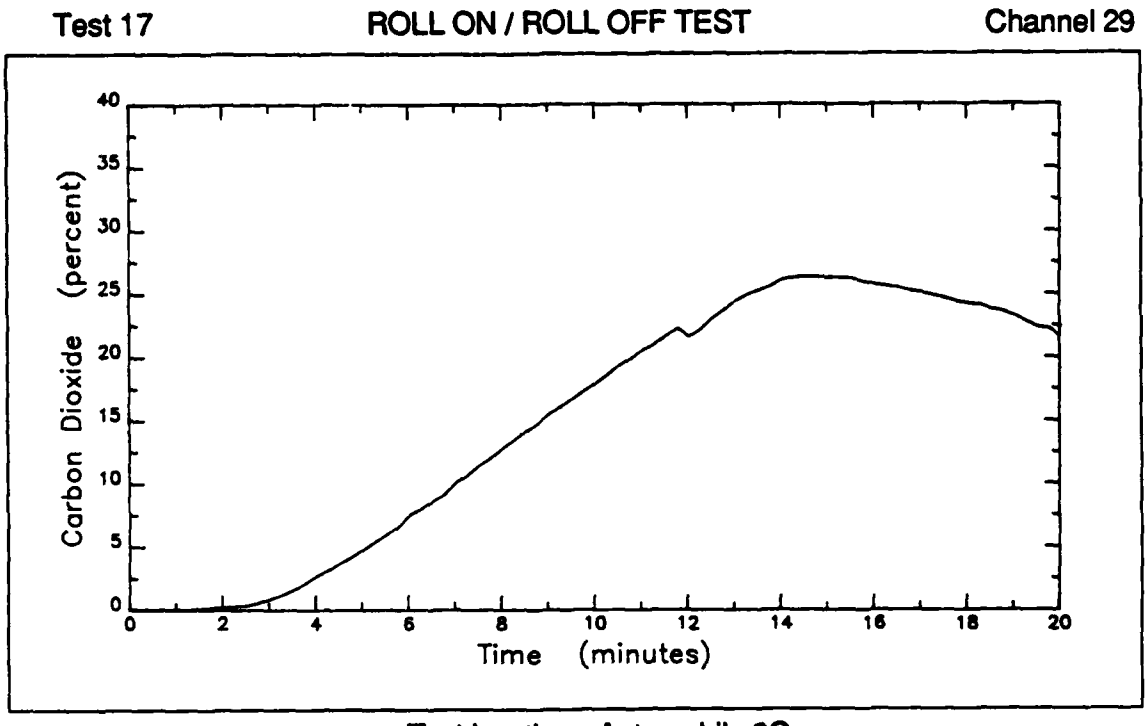



c. Test location - Automobile 11A

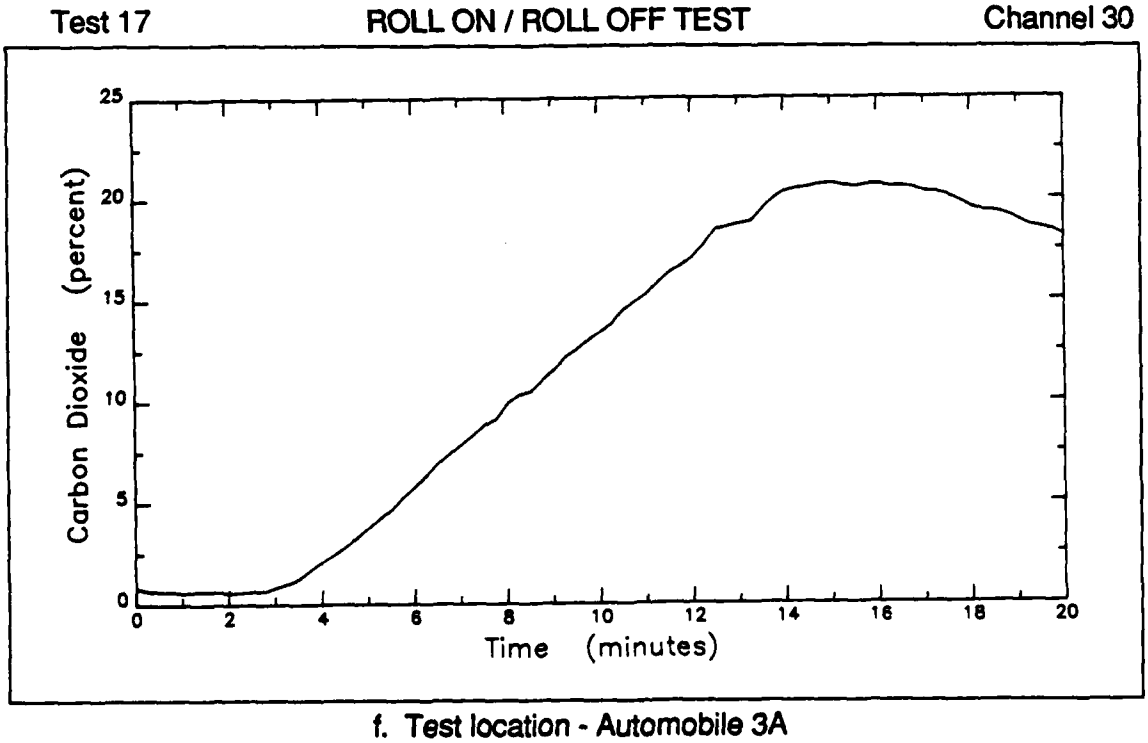



d. Test location - Automobile 12A

**FIGURE B 17-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

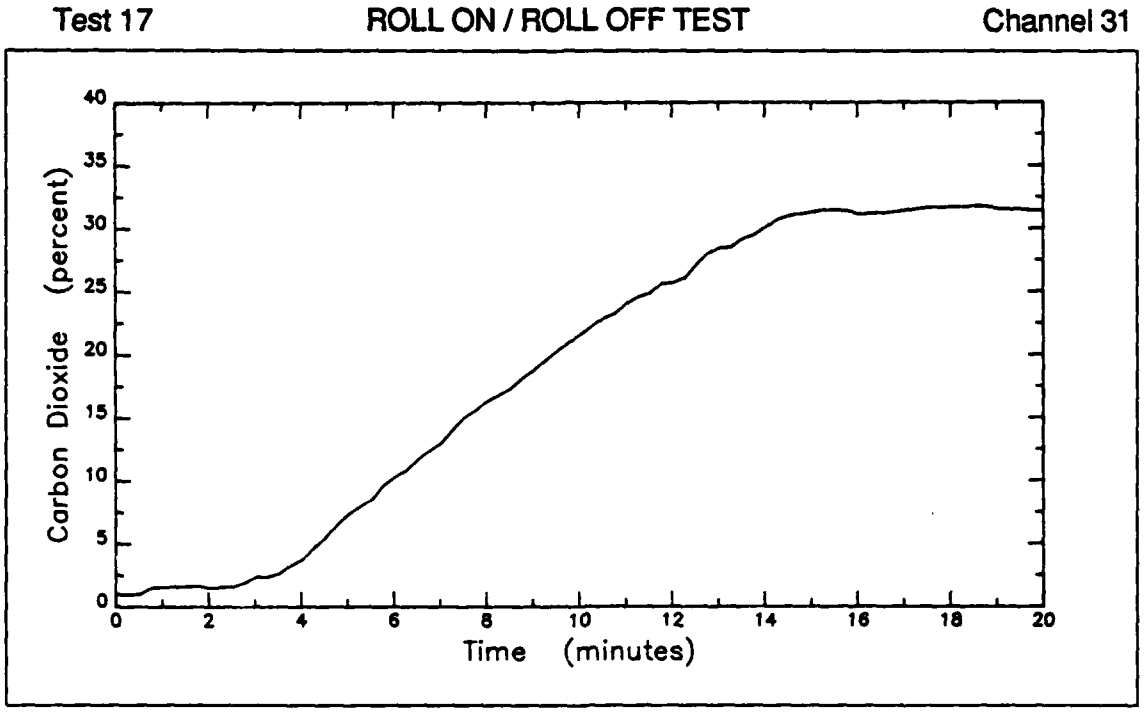



e. Test location - Automobile 9C

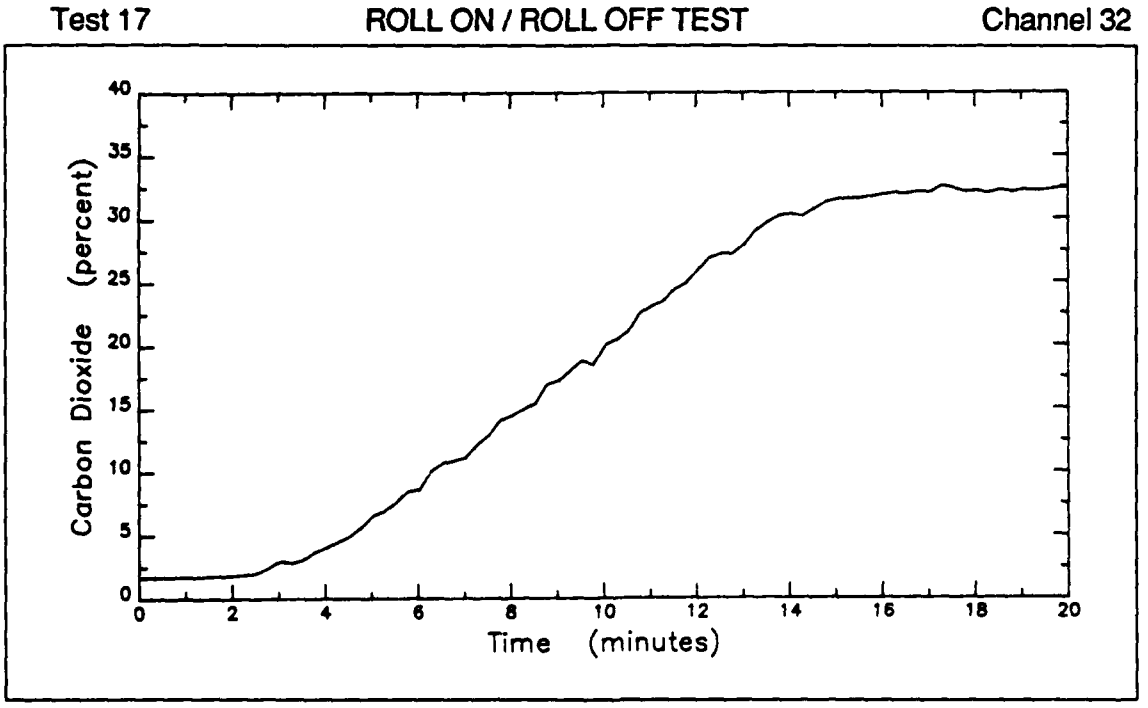



f. Test location - Automobile 3A

**FIGURE B 17-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

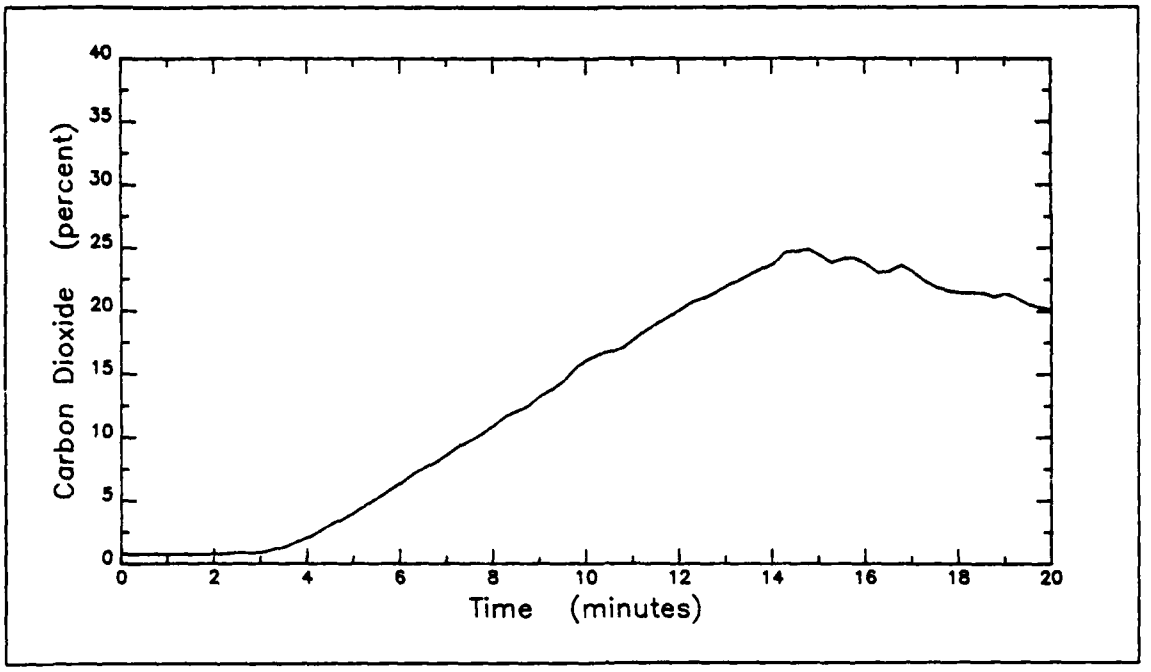



g. Test location - Automobile 9B




h. Test location - Automobile 12B

**FIGURE B 17-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**




i. Test location - Automobile 3B

**FIGURE B 17-8. PERCENT CARBON DIOXIDE vs TIME (cont'd)**

# APPENDIX C

## NOZZLE DATA

| Test | N-1* | N-2** | N-3*** | N-4**** |
|---|---|---|---|---|
| 1 | 7.84 + | 7.84 | 7.84 | 7.84 |
| 2 | 5.45 | 5.45 | 5.45 | 5.45 |
| 3 | 5.45 | 5.45 | 5.45 | 5.45 |
| 4 | 5.45 | 5.45 | 5.45 | 5.45 |
| 5 | 5.45 | 5.45 | 5.45 | 5.45 |
| 6 | 5.45 | 5.45 | 5.45 | 5.45 |
| 7 | 7.84 | 7.84 | 7.84 | 7.84 |
| 8 | 7.84 | 7.84 | 7.84 | 7.84 |
| 9 | 7.84 | 7.84 | 7.84 | 7.84 |
| 10 | 18.04 | 17.52 | 18.04 | 17.52 |
| 11 | 5.45 | 5.45 | 5.45 | 5.45 |
| 12 | 5.45 | 5.45 | 5.45 | 5.45 |
| 13 | 10.85 | 10.05 | 10.85 | 10.05 |
| 14 | 10.85 | 10.05 | 10.85 | 10.05 |
| 15 | 10.85 | 10.05 | 10.85 | 10.05 |
| 16 | 5.45 | 5.45 | 5.45 | 5.45 |
| 17 | 5.45 | 5.45 | 5.45 | 5.45 |

* N-1 Forward/Starboard Nozzle
** N-2 Aft/Starboard Nozzle
*** N-3 Forward/Port Nozzle
**** N-4 Aft/Port Nozzle

+ Equivalent Orifice Size
NFPA 12-1980, pp 1-10.4.4
Table 1-10.4.4(b) and Table 1-10.4.4(c)

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